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Sustainability of Agricultural Environment in Egypt: Part II

Soil-Water-Plant Nexus

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Aims and Scope

Since 1980, *The Handbook of Environmental Chemistry* has provided sound and solid knowledge about environmental topics from a chemical perspective. Presenting a wide spectrum of viewpoints and approaches, the series now covers topics such as local and global changes of natural environment and climate; anthropogenic impact on the environment; water, air and soil pollution; remediation and waste characterization; environmental contaminants; biogeochemistry; geoecology; chemical reactions and processes; chemical and biological transformations as well as physical transport of chemicals in the environment; or environmental modeling. A particular focus of the series lies on methodological advances in environmental analytical chemistry.

Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last three decades, as reflected in the more than 70 volumes of *The Handbook of Environmental Chemistry*, there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry*, the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of "pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Editors-in-Chief

Preface

This volume is divided into five parts comprising 18 chapters written by more than 20 researchers and scientists from Egyptian universities and associated research centers.

Part I is an introduction to the volume under the title “Rapid Soil Analysis using Modern Sensing Technology: Towards a more Sustainable Agriculture.” It presents the usefulness of modern sensing technologies in agriculture which have been given an important role for the improvement of agricultural production to keep up food security. These technologies include reflectance spectroscopy, visible near-infrared, and short-wave infrared (VNIR-SWIR).

Part II consists of four chapters dealing mainly with the ways of “Integrated Natural Resources Management for Sustainable Production.” The chapter titled “Effect of Water Deficit on Food Productivity Under Saline Conditions: Case Study – North Sinai, Egypt” presents and discusses the results of a trial field experiment on the saline soil in North Sinai to understand the response of commercial crop (faba bean) yield to differential water supply regimes. In the chapter titled “Land-Air and Water Resources on Sustainable Agricultural Development in Egypt,” the authors present the results of a model for determining reference evapotranspiration (ETo), crop coefficient (Kc) values, crop evapotranspiration (ETc), and evapotranspiration of applied water (ETaw). The model provides an estimate of the net irrigation water diversion needed to produce a crop. The application outputs include a wide range of tables and charts that are useful for irrigation planning and decision making. The chapter titled “Reclamation of Saline-Sodic Soils for Sustainable Agriculture in Egypt” presents and discusses the results of leaching experiments on a saline-sodic soil using soil column techniques to assess the efficiency of soil amendments of phosphogypsum (a gypsum-rich material, a by-product of superphosphate manufacture), standard gypsum, sulfuric acid, and rice straw experimentally. The last chapter in this section is titled “Impact of Tissue Culture in Agriculture Sustainability” and presents a state-of-the-art review of the plant tissue culture technique and its role in agriculture sustainability.

Part III comprises six chapters with the focus on "Integrated Biopesticides and Biofertilizers for Sustainable Agriculture." The chapter titled "Pesticide Alternatives Use in Egypt: The Concept and Potential" presents a comprehensive review of different pesticide options including plants' active components as pesticides (acaricides and miticides, bactericides and fungicides, herbicides, insecticides, and nematicides) and nanotechnology in pest management (nano-pesticides and metallic nanoparticles). The chapter titled "Biological Pest Control for Sustainable Agriculture in Egypt" discusses the status and potential of biological control in sustainable agriculture in Egypt through studying the abundance, the mass production, and the field application of natural enemies. Studied natural enemies include parasitoids, predators, predatory mites, and entomopathogenic nematodes. On the other hand, the chapter titled "Impact of Climate Change on Insect Pests of Main Crops in Egypt" presents an up-to-date review of the research findings on the impacts of climate change on the insect pests of the main crops in Egypt and shows how climate change affects the new evolution of these insects although they were evolved 500 million years ago. For a better plant health, the chapter titled "Integrated Pest Management for Sustainable Agriculture" reviews the up-to-date approaches in integrated pest management and discusses how to develop economically, socially, and environmentally acceptable pest control tactics using integrated pest management (IPM) and how IPM might be applied in Egypt. In addition, the chapter "Organic and Biofertilization on Crop Production in Semiarid Regions" discusses the importance of organic and biological fertilizers to increase the efficiency of the fertilizers of macro-elements, especially the nitrogenous ones, and their effects on the productivity and quality of barley grains growing under the conditions of semiarid regions, especially those suffering from salt stress. The chapter titled "Using Humic Substances and Foliar Spray with *Moringa* Leaf Extract to Alleviate Salinity Stress on Wheat" aims to present and discuss the results of investigating the effect of humic substance with or without foliar spraying Moringa leaf extract (MLE) on Sudan grass yield, photosynthetic pigments, nutrient uptake, and available N, P, and K in saline loamy soil under local weather conditions.

Part IV consists of four chapters dealing with "Integrated Fish, Plant and Animal for Sustainable Food Supply." In the chapter titled "Importance of Forage Mixtures in Increasing Sustainable Food Supply in Egypt", the authors present the important role of forage cultivation in increasing the land use efficiency and utilization of environmental resources with a focus in the forage mixtures which succeeded under Egyptian conditions including the following: Sudan grass-cowpea, fodder maize-cowpea, fodder maize–guar, ryegrass-clover, barley-clover and canary grass-clover. While in the chapter titled "Algae and Chain Aquaculture: An Approach Towards Sustainable Agriculture," the author discusses a proposed working model in which algae play major roles in the different global ecosystems. The proposed model is based on using the innovative strategy of integrating the culturing of algae, fish, and plants in a sustainable aquatic chain. Under limited water resources, unpolluted underground water, which is mostly brackish, provides a solution to be used for establishing algal and fish cultures. In the chapter titled

"Managerial and Nutritional Trends to Mitigate Heat Stress Risks in Poultry Farms," the authors present the effects of heat stress on the rural poultry production and discuss the strategies to mitigate the impact of heat stress on poultry. The chapter "Nutritional Strategies to Produce Organic and Healthy Poultry Products" offers a simple overview of the significance and health benefits of organic poultry products, and it explores the possibilities of the production and development of organic food by technological strategies. The last chapter in this section is titled "Ways to Minimize Nitrogen Emissions in Agricultural Farms." The chapter reviews the farming types and the sources of emission in the agricultural farms. Also, the authors discuss ways to reduce the nitrogen emissions via beneficial microorganisms and other methods.

The last part of the volume consists of two chapters dealing with the "Policies that Work for Sustainable Agriculture in Egypt" and the conclusions chapter, which summarizes the covered topics in this volume with an update of the recently published research, highlights the extracted conclusions from the chapters, and presents a set of recommendations for further future research on sustainable agriculture environment.

The editors would like to express their special thanks to all those who contributed in one way or another to make this high-quality volume a real source of information on sustainable agriculture environment in Egypt supported by the latest findings in the field summarized to support graduate students, researchers, scientists, and decision/policy makers in Egypt and everywhere who are interested in the coastal lakes.

Much appreciation and great thanks are due to all the authors who contributed to this volume. Without the efforts and patience of all the contributors in writing, reviewing, and revising the different versions of the chapters, it would not have been possible to produce this unique volume titled *Sustainability of Agricultural Environment in Egypt: Soil-Water-Food Nexus*. Also, special thanks are due to the Springer team and editors of HEC series who largely supported the authors and editors during the production of this HEC volume.

The volume editor would be happy to receive any comments to improve future editions. Comments, feedback, suggestions for improvement, or new chapters for next editions are welcome and should be sent directly to the volume editor.

Zagazig, Egypt — Abdelazim M. Negm
Zagazig, Egypt — Mohamed Abu-hashim
23 April 2018

Contents

Part I
Introduction

Rapid Soil Analyses Using Modern Sensing Technology: Toward a More Sustainable Agriculture

El-Sayed Ewis Omran

Abstract Modern sensing technology must be utilized to provide farmers with rapid soil analysis in making farming more sustainable. Modern technologies in agriculture have been given an important role for the improvement of agricultural productions, e.g., sustainable agriculture, in order to maintain food security. It has been known that modern agricultural technology can sustainably improve agricultural production. Up-to-date information on soil properties is imperative for sustainable agriculture. Conventional soil analyses cannot efficiently give this information since they are slow and expensive and sometimes incorporate environmentally damaging chemicals. Soil spectroscopy is a well-known technique to assess soil properties quickly and quantitatively.

To assess the utility of spectroscopy for soil characteristic (clay content, salinity, and OM) prediction, 35 soil samples collected from Bahr El Baqar, Egypt were scanned in the 350–2,500 nm region (FieldSpec Spectroradiometer). Reflectance spectroscopy gives an alternate method to nondestructively characterize key soil properties. Chemometrics techniques have been utilizing to estimate soil properties from visible and near-infrared (VNIR, 350–1,200 nm) and shortwave-infrared (SWIR, 1,200–2,500 nm) reflectance domains. Partial least squares regression (PLSR) was put in place to develop calibration models, which were independently tested for the predictions of soil organic carbon, salinity, and clay content from the soil spectra. Some spectral data pre-processing techniques were carried out to diminish noise, to offset effects, and to improve the linearity between measured absorbance and soil properties. These models were developed by the correlation between spectral characteristics and physicochemical soil properties separately for each soil property, using PLSR analysis. The continuum removal (CR) spectra yielded the best calibration models with respect to estimates of the soil salinity,

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which generated R^2 values of 0.62. In the case of the clay content, the prediction capacity of the method proved to be high ($R^2 = 0.57$) using CR. These results can be explained by the strong spectral activity of organic carbon and clay in the VNIR-SWIR region. The model accuracy (RMSE OM = 0.425) is low, indicating the need for improving the measurement protocol to achieve more reliable data and to test other pre-processing and modeling methods as well. The deviation of the arch (DOA) at 600 nm is indicative of the convex and concave features of the spectral curves generated by OM. The DOA contains the majority of information regarding OM and can be utilized to estimate OM.

Keywords Bahr El Baqar, Chemometrics, Egypt, Partial least squares regression, Sensing technology, Soil analyses, Spectroscopy, Sustainable agriculture

Contents

1 Introduction

Technology advancement must be utilized to provide farmers with rapid soil analysis in making farming more sustainable. Modern sensing technologies in agriculture have been given an important role for the improvement of agricultural productions, e.g., crop yield, animal production, aquaculture generation, and sustainable farming, to keep up food security. It has been realized that up-to-date agricultural innovation can economically enhance agricultural production. As agriculture is a major contributor to the increasing environmental damage, change toward a more sustainable way of farming is needed. Up-to-date information on key soil properties is imperative for sustainable agricultural and environmental management. Conventional soil sampling and laboratory analyses cannot efficiently give this information since they are slow and expensive and sometimes incorporate environmentally damaging chemicals. Its high costs have hindered the introduction of precision agriculture in several parts of the world [1]. The cost for conventional soil characterization is about US$2,500 per pedon and requires 6–12 months to be done [2–4]. So, the traditional soil analysis appears to be irrelevant to many users and does not possess "a market with land administrators and policy makers" [5]. Thus, an accelerated and environmentally friendly method is expected to analyze soils rapidly. One of the cost-effective methods in soil analysis is the reflectance spectroscopy. A growing demand for high-resolution spatial soil information for precision farming leads us to an exploration question: Can spectroscopy replace the outdated methods of soil analyses?

Soil reflectance spectroscopy is a well-known technique to assess soil properties quickly and quantitatively [6]. Reflectance spectroscopy is relatively less costly and quicker than traditional wet chemical measurements [7]. Visible and near-infrared and shortwave-infrared (VNIR-SWIR) reflectance spectroscopy is a promising tool for the productive identification and monitoring of soil properties in the spectral range 350–2,500 nm, "because of the occurrence of robust spectral features inferable to soil constituents in this region" [8–10]. However, the relevant information for soil characteristic prediction should be mathematically extracted from the spectra so it can be linked to soil attributes. Chemometrics technique and multivariate statistical methods [11, 12] must be utilized to examine the relationships between reflectance spectra and soil properties. Partial least squares regression (PLSR) is viewed foremost method, which has been developed to relate the soil spectrum to soil attributes. The PLSR performance is usually high and clarifies more than 80% of the soil variability [13, 14]. PLSR has been frequently successful than other models [15–17] as it deals with serious collinearity, it is suitable for the sample number less than the variable number, and it considers both the independent and dependent variable. However, PLSR is not able to remove the noise band or the irrelevant variables. Thus, useless information may influence the model to uncover a more reasonable relationship. Therefore, it is useful to utilize a PLSR-based band selection and transformation procedure [6].

The choice of the spectral pre-processing method [18] was observed to be crucial for the performance of multivariate calibration. Albeit numerous transformation methods have been proposed, the decision of which pre-processing to utilize is minimally known. Since the right method can improve the predictive capability of the models [19, 20], this research aims to advance the use of VNIR-SWIR spectroscopy for soil property prediction of Bahr El Baqar region, Egypt. The present study is geared toward building up a rapid spectroscopic method for soil property determination. The main objective is to test the capability of PLSR for predicting soil organic matter (OM), clay content, and salinity using VNIR-SWIR spectroscopy. To achieve the main objective, the following specific questions are examined in this study:

1. Is there variation within the spectra of soil samples that allow differentiation between different soil properties?
2. What impact do different transformations have on the soil sample signature?
3. Can PLSR be used to model the key soil properties from soil spectra and reference chemical measurements in the area, where ground data is not accessible?

2 VNIR-SWIR Spectra of Soil Properties

Many soils and agricultural applications do not always be precisely quantified, but only require a soil classification with respect to a critical test value for key soil properties (e.g., clay content, salinity, and OM). Shepherd and Walsh [21] utilized the laboratory VNIR analysis for the soil discrimination, falling above or below specific cutoff values for most key soil properties, which influence soil fertility and productivity. VNIR-SWIR spectroscopy could be a promising technique for the prediction of soil (physical, chemical, and biological) properties [19, 22–24]. The results of the VNIR-SWIR prediction models of soil properties are summarized in Table 1. Different modeling techniques, as well as various pre-processing methods, were employed in the development of these models.

Regarding soil chemical properties, various authors have reported accurate VNIR-SWIR spectroscopy predictions of soil total C and N [40] and pH [21]. This is reliable, considering that numerous bonds between C and O, N or H absorb light in the near-infrared (NIR) region, while pH prediction has been attributed to O–H groups [41]. Good predictions have also been achieved for K [21] and for soil P and N [21, 41–43]. Contradictory predictions have been reported for electrical conductivity [41], organic carbon [44, 45], and salinity [1, 13, 14, 35–38]. The OM has distinctive spectra, particularly in the NIR due to the formation of covalent bonds with a variety of molecules [46]. Some studies have indicated that the prediction of soil OM was better in the visible range at 410, 570, and 660 nm [24, 47] where a few scientists had announced a substantial relationship between OM in soil and spectral reflectance in the range 545–830 nm [48].

Table 1 Summary result of soil property prediction via VNIR-SWIR spectroscopy

Soil properties	Number of samples/R^2	Modeling method	Author
Organic carbon	420/>0.73	MLR	[25]
	48/>0.72	SMLR	[26]
	273/0.96	PLSR	[27]
	105/0.69	PLSR	[28]
	400/0.88	PLSR	[29]
	3,793/0.82	BRT	[3]
	180/0.85	PLSR	[30]
	118/0.6	PLSR	[24]
	165/0.92	PLSR	[31]
	40/0.80	PLSR	[32]
Clay and sand content	100/>0.60	PLSR	[33]
	235/0.80	PLSR	[34]
Soil salinity	94	PLSR/MARS	[1, 35–38]
	165/>0.87	PLS/SVR	[39]

MLR multiple linear regression, *SMLR* stepwise multiple linear regression, *BRT* boosted regression trees, *PLSR* partial least squares regression, *MARS* multivariate adaptive regression splines

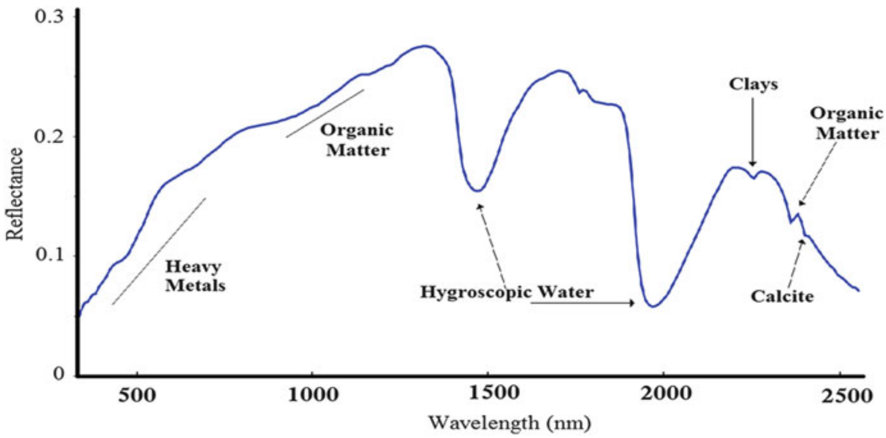

Fig. 1 Reflectance spectra of soil sample indicating the spectral features of the most important constitutes

Reflectance spectroscopy has been applied to predict soil physical properties, such as texture and clay content [11, 49]. VNIR has yielded good results for soil particle size distribution [50], soil moisture [51], water holding capacity [52], infiltration of crusted soils [53], maximum temperatures reached by burned soils [52, 54], and total clay content [7, 55]. The spectral properties of clays are most dominant in the NIR area where unique absorption bands can be utilized to give quantifiable data on clay mineralogy [56]. Figure 1 displays the main characteristics of spectral signatures and corresponding soil attributes and also "shows certain main spectral regions for some soil characteristics" [6].

3 Prediction of Soil Properties Using Spectroscopy Technique

3.1 Soil Chemical and Spectral Analysis

The study area, Bahr El Baqar region, is located in northern Egypt between 31° 50′–32° 20′ longitude and 30° 40′–31° 10′ latitude (Fig. 2). Soils, which are neighboring to El Manzala Lake, are defined as heavy saline-alkali low-lying clay, which is lacustrine deposits. The land surface is level, slightly sloping to the north, and ranges in elevation from below sea level to 4 m (a.s.l) in the highest point [57]. A reconnaissance field trip was achieved in the study area to be familiar with different landscape features: land-use and land cover patterns. The field surveys were directed with a global positioning system (GPS) receiver.

Soils were categorized by their main physicochemical characteristics. A total of 35 soil samples were collected from Bahr El Baqar, Egypt (Fig. 2). Soil samples

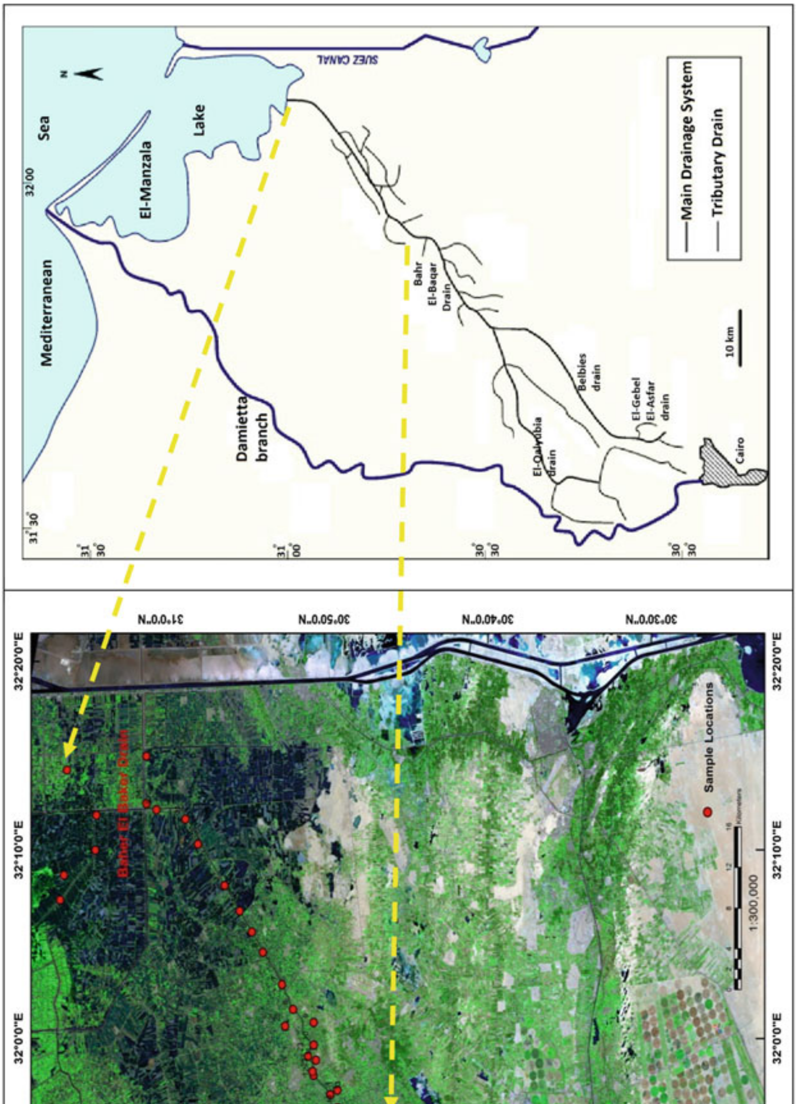

Fig. 2 Footprints and Landsat 8 image for selected sample locations in the study area

were collected randomly from selected agricultural fields from the upper horizon, which was air-dried and sieved. Each soil sample was equally divided into two parts, one for chemical analysis by a typical method and the other part for spectral measurements. Soil reflectance spectra are collected using a portable spectroradiometer (FieldSpec Pro, Analytical Spectral Devices), which measures reflectance over a range from 350 to 2,500 nm with a resolution of approximately 10 nm and a sampling interval of 3 nm [6]. For each sample, two spectral measurements were averaged. Outliers were examined on all these data, and one sample was removed. Thirty-four samples remained for soil property modeling and analysis.

One examined soil physical property (clay content) and two soil chemical properties (salinity and organic matter) were quantified. "Particle size distribution was measured by the pipette method" [58]. The electrical conductivity (EC) of soils was determined using 1:2 soil to solution (H_2O) ratio. Soil pH was determined in deionized water (pH_w) and in 0.01 M $CaCl_2$ (pH_{CaCl2}) (in 1:2.5 suspensions). Organic carbon (OC) was analyzed by the wet digestion [59].

3.2 Steps Used to Predict Soil Properties

The application of VNIR-SWIR spectroscopy for soil property prediction does not involve any (hazardous) chemicals. It is a nondestructive technique well suited for analyses of some of the essential constituents of the soil [60]. The sample only takes a few seconds, and several soil properties can be estimated from a single scan. Moreover, it allows for flexible measurement configurations and in situ as well as laboratory-based measurements. Thus, for the purpose of this research, Fig. 3 proposes the methodology used.

3.3 Pre-processing Techniques and Transformations

Different pre-processing techniques (e.g., averaging, smoothing, standardization, and normalization) were utilized to expel any inappropriate information, which cannot be controlled correctly by the modeling procedures. Spectral pre-processing algorithms were tested to reduce noise or enhance the spectra or both.

Three factors gave the impetus for data reduction and averaging. First, the spectra were all smoothly changing, with no unexpected transitions such as sharp peaks or valleys. It was anticipated that no substantial spectral information would be lost using an averaging procedure. Second, correlation data for the complete set of wavelengths indicated high correlations between reflectance values at widely contrasting wavelengths. These correlations were greatly distinguished between nearly adjacent wavelengths. Thus, it was also expected that substantial predictive power would not be lost because of averaging. Finally, computational demands for choice methods increase exponentially with the number of initial independent

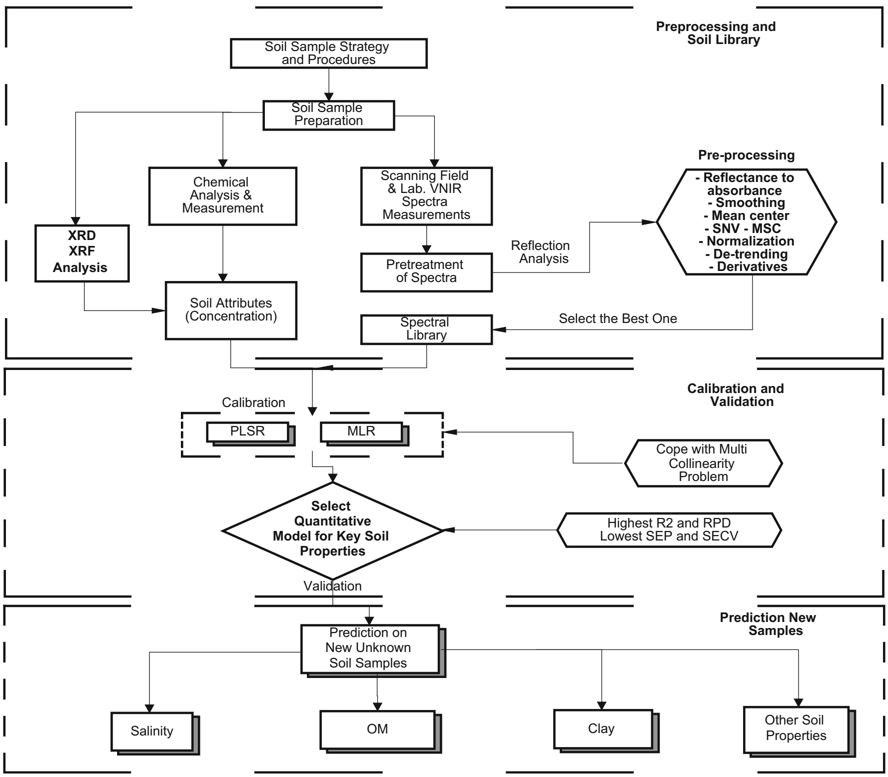

Fig. 3 The overall steps used in this research to predict key soil properties using spectroscopy and chemometrics technique

variables. Selecting a subset from 2,151 variables would be extremely time intensive. These reflections lead to a conclusion to utilize averaged spectral data. Spectral averaging comprised of a 10 nm boxcar strategy at wavelength intervals of 10 nm from 350 to 2,500 nm and was achieved using spreadsheet software. Thus, the new spectrum comprised of reflectance values at 350, 360, 370,… 2,500 nm, inclusive. This technique leads to a new dataset, with reflectance values quantified for 214 wavelengths for all samples, that was approximately 1/10th the original data volume while maintaining sufficient spectral information [6].

A multiplicative scatter correction (MSC) is a standout among the most generally utilized normalization procedures. In MSC, the light scattering is assessed for each sample with respect to an ideal sample acquired by averaging the complete wavelength range of the dataset. Each spectrum is then corrected such that all samples seem to have a similar scatter level as the reference spectrum [61]. Spectroscopic measurements were achieved in the transmission mode, which can be computed to absorbance using Beer's Law [62]. The measured reflectance (R) was converted to apparent absorbance as log10(1/R). The Kubelka-Munk transformation is similar to absorbance, but accounts for scattering [62].

Continuum removal (CR) was figured using a convex hull [63], which is fitted to the spectrum, and the spectrum is then divided at each wavelength by the hull. The CR value can be obtained by dividing the corresponding reflectance value of the reflectance level of the convex hull at the corresponding wavelength, with the constraint that its maximum value could not be greater than 1. With the CR technique, the reflectance spectra are standardized permitting correlation between absorption features, for example, depth, depth position, the area of the absorption, etc. These features can be figured from a continuum-removed spectrum to improve absorption features in the recorded soil reflectance spectra. The CR will limit any brightness differences and emphasize the spectral absorption bands.

Derivatives were often used to remove baseline shifts and superposed peaks. The 1st derivative of spectra removes additive baseline ("offset") effects that could be ascribed to the roughness of soil samples. Second derivative spectra can correct for both additive and multiplicative effects (like MSC). They are generally computed by Savitzky-Golay algorithm [64], which yielded the best transformations in pre-processing [65]. A second-order polynomial was utilized. Utilizing derivatives of the spectra may enable pertinent information to be separated from the near-infrared range [66]. The parameters of the calculation (interval width, polynomial order) should be carefully selected to avoid enlargement of spectral noise [62].

3.4 Development of Calibration Models for Soil Property Prediction

Modeling refers to relate a set of spectral parameters that are derived from the spectral information (after the pre-processing treatment) to the real soil properties. Various algorithms can be utilized to calibrate soil VNIR-SWIR spectra to predict soil properties. They incorporate multiple linear regression (MLR), principal component regression (PCR), and partial least squares regression (PLSR) as well as data mining techniques like artificial neural networks (ANN), multivariate adaptive regression splines (MARS), and boosted regression trees [12]. The linear ones are more straightforward and most commonly used. In the meantime, the use of data mining is increasing, particularly for vast, diverse datasets where data mining is indicated to perform slightly better than linear analyses [12].

The spectral measurements were compared with their equivalent chemical measurements. Then multivariate models were constructed and tested to predict each soil property. PLSR is a technique widely used in chemometrics (e.g., [6, 34, 38]) when there are many predictor variables, highly collinear. The main advantage of multivariate analysis using PLSR calibration is its ability in the fast determination of the components in mixtures, especially with signal overlapping. PLSR is based on the latent variable decomposition of two sets of variables: the predictor X, which is the spectral reflectance bands (independent data), and the responses Y that are the soil property (dependent) data. PLSR selects orthogonal factors that maximize the covariance between the independent (*X*) and the dependent variables (*Y*), where the limited number of PLSR factors selected explains most of the variation in both predictors and responses. The PLSR analysis was carried out using Unscrambler 10.4 software [67].

The PLSR analysis was applied to the raw reflectance and to the different transformation methods. PLSR analysis between one attribute (clay content, salinity, or OM) and the spectral data (average spectra in the range from 350 to 2,500 nm) was conducted using spectroscopy. Most of the variation can be captured within the first few latent variables/factors, while the remaining latent variables describe random noise or linear dependencies between the wavelengths/predictors. This process amplifies the "peakedness," which is considered advantageous for noisy and scattered data. The soil analysis data determined by conventional chemical analysis techniques were added to the resultant spectral files using the WinISI II (Ver. 1.04) (FOSS NIRSystem/TECATOR, 1999). Matlab (version 8.1.347) and PLS-Toolbox 4.2 were used to fit partial least squares regression (PLSR) calibration with leave-one-out cross-validation.

3.5 Prediction Accuracy

The samples were randomly divided into two sets to develop the statistical model of each soil property: a training set (25 samples = 75% of the total database) for developing the prediction model and a validation set (9 samples = 25% of the total database) to test the accuracy of the model. As few as 25 samples can result in better predictions at the farm or field scale [6, 56]. One hundred to two hundred samples might be at the lower limit for a model planned to cover a large area with various soil types [6, 60]. The choice of the ideal number of PLSR components is a key step to getting a calibration model with good predictive power, which is done via cross-validation of calibration samples. The cross-validation was performed using the leave-one-out method [68]. To quantify the goodness of prediction models, the coefficient of determination (R^2) and root mean square error (RMSE) was used. The aptitude of the reflectance procedure to predict a soil property was estimated by the lowest standard error of prediction (SE_P), the lowest root mean square error of prediction ($RMSE_P$), and the highest coefficient of correlation.

4 Rapid Soil Analysis Using Spectroscopy

4.1 Physicochemical Properties of the Bahr El Baqar Soils

Table 2 shows a summary descriptive statistics of representative physicochemical properties of the Bahr El Baqar soils. The mean, standard deviation, and range for

Table 2 Summary descriptive statistics of representative physicochemical properties of the Bahr El Baqar soils

Properties	Minimum	Maximum	Range	Mean	Std. deviation	CV	Skewness	Kurtosis
Salinity (dSm^{-1})	0.93	15.00	14.07	4.97	3.87	14.94	1.33	0.96
OM %	0.22	3.55	3.33	1.60	0.79	0.62	0.73	0.69
pH	7.58	8.82	1.24	8.00	0.30	0.09	0.81	0.25
Sand %	2.60	95.72	93.12	43.00	25.83	667.07	0.16	−0.78
Silt %	1.04	56.89	55.85	30.38	12.93	167.09	−0.20	0.43
Clay %	3.24	80.00	76.76	26.61	24.52	601.14	1.01	−0.51

Table 3 Pearson (parametric) rank order correlations

	Salinity	OM	pH	Sand	Silt	Clay
Salinity	1					
OM	−0.413[a]	1				
pH	−0.469[b]	0.220	1			
Sand	0.073	−0.565[b]	−0.524[b]	1		
Silt	0.548[b]	−0.066	−0.150	−0.349[a]	1	
Clay	−0.366[a]	0.630[b]	0.631[b]	−0.869[b]	−0.160	1

[a]Correlation is significant at the 0.05 level (2-tailed)
[b]Correlation is significant at the 0.01 level (2-tailed)

each soil property are presented in Table 2. The pH of the Bahr El Baqar soil solution maintained at the alkaline condition with average 8.00. It could be attributed to the presence of calcareous parent material. The relatively high content of OM (average 1.6%) is mainly related to the high OM flux to the soil due to direct discharge of domestic and industrial wastewaters.

The mean value of sand, silt, and clay in the soil is 43.00, 30.38, and 26.61%, respectively. The range of the minimum and maximum values is 93.12, 55.85, and 76.76%, respectively, which is large. There are great variations and high skewness for clay (1.01). CV percentage values reflect the mean variation of each sampling site in the population. The order of the CV % for each element from high to low was sand, clay, and silt. To determine the relationship among key soil parameters, Pearson correlation coefficients were calculated (Table 3). The results revealed that the OM is good correlated with clay and moderately correlated with silt (r = 0.630 and 0.565, respectively). Furthermore, there is a good correlation between salinity and silt ($r = 0.548$).

4.2 Rapid Spectral-Based Models to Predict Key Soil Properties

4.2.1 Overall Soil Spectral Analyses

Figure 4 illustrates the spectra of all soil samples measured in the laboratory. In each region of the wavelength domain, soil spectra plotted to display the typical soil reflectance shape. Reflectance is generally lower in the visible range (350–650 nm) and higher in the near infrared with specific absorbance bands around 1,400, 1,900, and 2,200 nm.

4.2.2 Calibration Models for Key Soil Properties

Table 4 summarizes the cross-validation results of the PLSR models developed with raw and various pre-processing transformed VNIR-SWIR spectra against each soil property. For raw spectra, PLSR models produced poor prediction accuracy with R^2 of 0.22, 0.38, and 0.46 and RPD of 1.73, 0.93, and 0.94 for soil clay, salinity, and OM, respectively. However, with appropriate spectral pre-processing algorithms, model performance was improved to a certain degree. For example, PLSR model developed for clay after CR transformed spectra resulted in R^2 of 0.52 and RPD of 3.75. By using the second derivative pre-processing technique, prediction of soil salinity was improved with R^2 of 0.62 and RPD of 3.44. The best calibration model for OM (R^2 of 0.44 and RPD of 3.75) was obtained when the spectra were transformed by MSC followed by a de-trending technique. It is worth noting that these optimized PLSR models need less latent variables (3–5) than those for raw spectra. In general, the fewer the latent variables used, the better is the model developed. For clay content, PLSR calibration with raw and various transformed spectra failed to produce useful models.

4.2.3 Modeling Transformed Spectra (TS) of Soil Clay Content

The absorption feature of clay content in the VNIR-SWIR region can be better analyzed using CR transformed spectra (TS_{cr}) (Fig. 5 and Table 4). The dominant absorption features near 1,400 nm (TS_{cr1400}) and 1,900 nm (S_{cr1900}) should be related to the presence of both hydration and crystallization water. Moreover, since TS_{cr1400} should also be related to the –OH vibration of water in silicates, it could be used to indirectly explain the percentage of the sand fraction that is constituted by these minerals. The absorption peak at 2,200 nm should be ascribed to the –OH-Al bending modes, as observed in various clay soils. Therefore, TS_{cr2200} can be directly used to explain clay fraction of spectral data. The CR values at 1,400 (TS_{cr1400}) and 2,200 nm (TS_{cr2200}) extracted from continuum-removed spectral

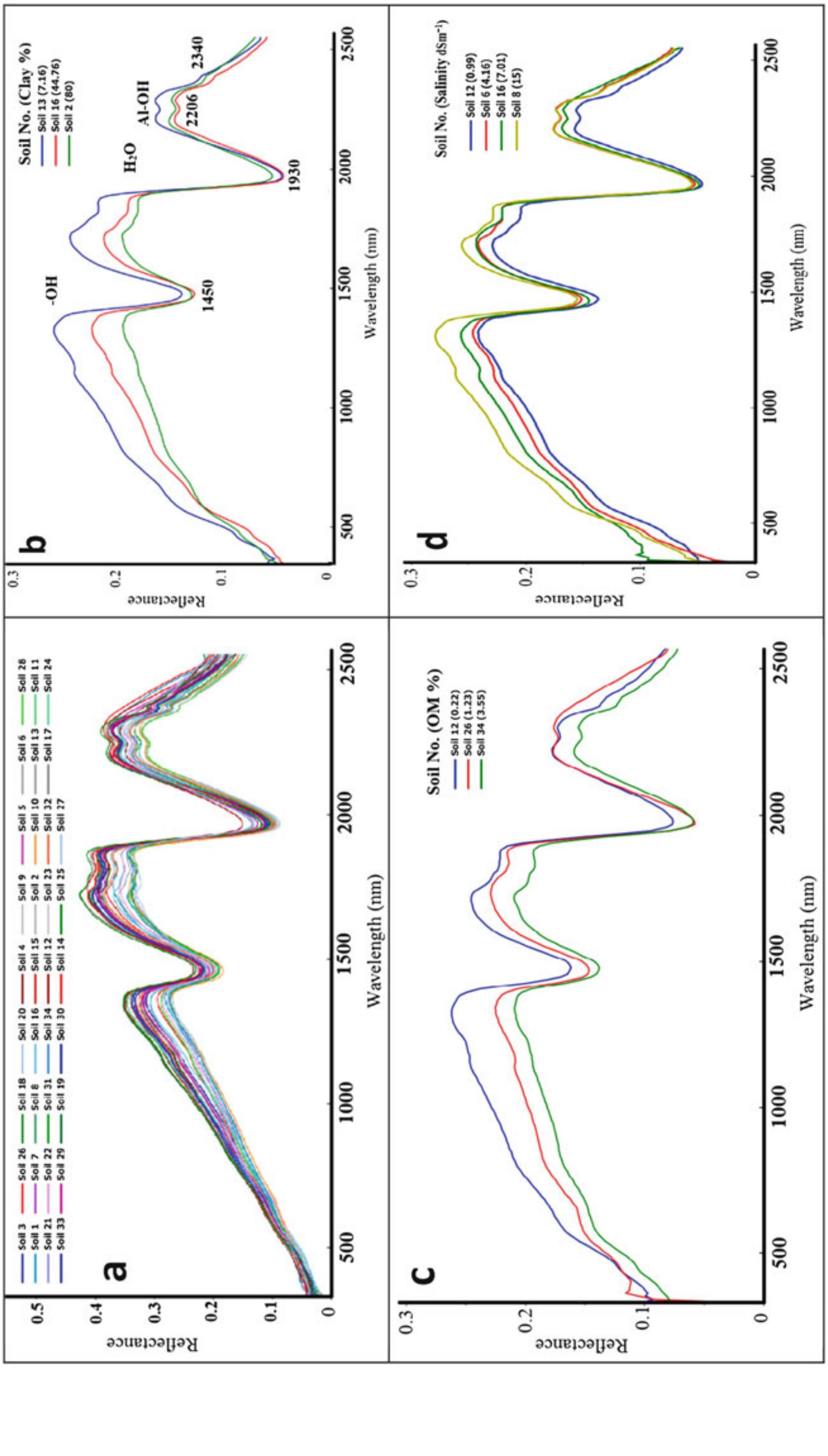

Fig. 4 **(a)** Reflectance curves obtained from the measured reflectance of soil samples, **(b)** soils with different clay content, **(c)** soils with different organic matter, and **(d)** soils with different salinity levels

Table 4 VNIR-SWIR cross-validation of PLSR for predicting key soil properties

Spectral pretreatment methods					Scatter correction methods						Spectral derivatives				12	13	14	15
								7-Normalization			8-Savitzky-Golay smoothing	Derivative						
		1-Raw refl	2-log (1/*R*)	3-Mean center	4-MSC	5-SNV	6-De-trending	Max	Range	Quantile		9-1st	10-2nd	11-CR	4–6	2–3–8–9	2–3–8–10	2–3–8–11
Clay content	R^2	0.22	0.26	0.33	0.25	0.26	0.29	0.38	0.30	0.25	0.29	0.29	0.31	0.27	0.25	0.33	0.36	0.49
	RPD	1.73	0.96	0.96	0.88	0.86	0.97	0.98	0.97	0.82	0.98	0.95	0.89	0.94	0.98	0.97	0.94	1.90
	SE_{CV}	25.64	26.05	25.98	28.25	28.92	25.56	25.34	25.59	30.29	25.48	26.07	27.856	25.52	25.49	25.61	26.52	22.52
	SE_P	25.26	25.67	25.59	27.87	28.52	25.19	24.97	25.21	29.84	25.09	25.68	27.46	26.13	25.09	25.23	26.13	21.51
	RMSE	24.34	24.19	24.10	23.24	22.53	24.41	24.51	23.97	21.58	24.41	24.26	23.00	23.99	23.07	24.33	23.99	21.99
Salinity	R^2	0.38	0.40	0.45	0.46	0.41	0.15	0.46	0.39	0.41	0.49	0.45	0.42	0.38	0.40	0.39	0.57	0.55
	RPD	0.93	0.93	0.93	0.89	0.92	0.87	0.98	0.97	0.87	0.91	0.90	0.95	0.37	0.89	0.92	1.31	1.28
	SE_{CV}	3.464	3.701	3.541	3.559	3.719	3.532	3.823	3.777	3.435	3.380	3.841	3.847	0.96	3.535	3.827	3.725	3.701
	SE_P	4.228	4.209	4.227	4.391	4.276	4.497	4.006	4.033	4.528	4.338	4.361	4.118	3.761	4.409	4.255	4.354	4.343
	RMSE	4.17	4.15	4.16	4.33	4.21	4.43	3.95	3.97	4.47	4.27	4.30	4.06	4.024	4.34	4.19	2.95	2.90
Organic matter	R^2	0.46	0.39	0.41	0.49	0.45	0.42	0.38	0.40	0.39	0.45	0.46	0.41	0.15	0.42	0.38	0.40	0.39
	RPD	0.94	0.94	0.95	0.84	0.87	0.94	0.94	0.92	0.83	0.96	0.97	0.92	0.81	1.61	0.96	0.93	0.99
	SE_{CV}	0.786	0.7923	0.796	0.759	0.786	0.798	0.790	0.729	0.744	0.797	0.800	0.796	0.7701	0.764	0.802	0.796	0.835
	SE_P	0.854	0.852	0.840	0.956	0.921	0.849	0.851	0.869	0.969	0.837	0.823	0.869	0.724	0.923	0.832	0.866	0.847
	RMSE	0.84	0.84	0.83	0.94	0.91	0.84	0.84	0.86	0.96	0.83	0.81	0.86	0.73	0.49	0.82	0.85	0.84

R^2 coefficient of determination, *RPD* residual prediction deviation, SE_{CV} standard error of cross-validation, SE_P standard error of prediction, *RMSE* root mean square error of calibration, *SNV* standard normal variate, *MSC* multiple scatter correction, *CR* continuum removal

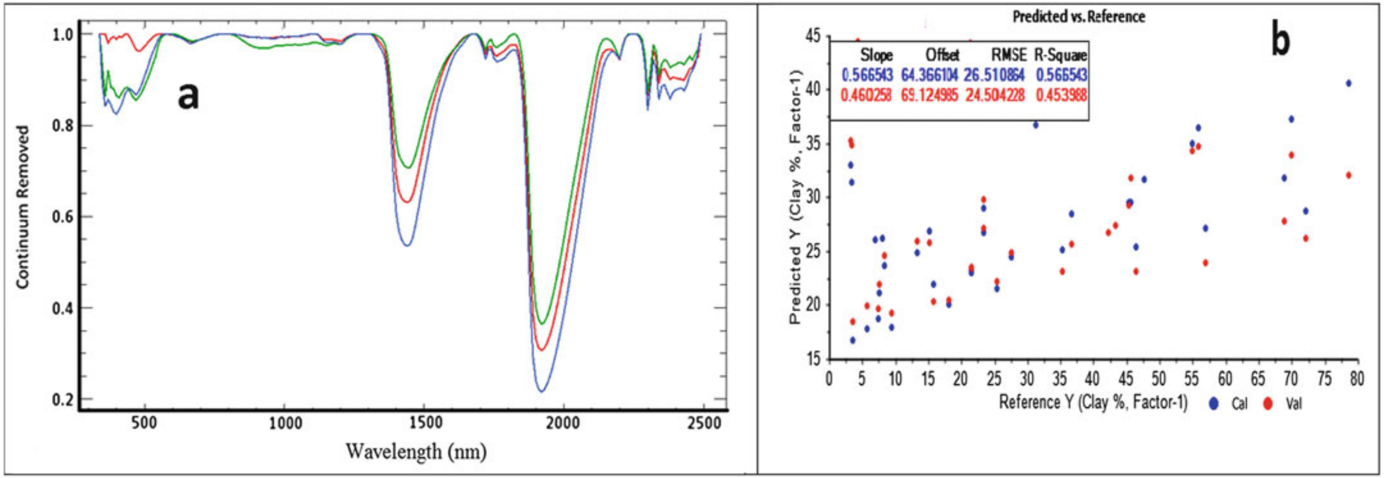

Fig. 5 Continuum-removed spectra and reflectance curves. (**a**) Soils with different clay content and measured vs. predicted soil texture using the CR approach (**b**)

dataset were linearly correlated with measured clay and sand fractions (%) in the prediction of soil texture:

$$\text{Clay}\ (\%) = a_1 + b_1\ \text{TS}_{\text{cr2200}} = 28.15 + (-0.092 \times \text{TS}_{\text{cr2200}})\ \left(R^2 = 0.57\right) \quad (1)$$

$$\text{Sand}\ (\%) = a_2 + b_2\ \text{TS}_{\text{cr1400}} = 37.91 + 0.289 \times \text{TS}_{\text{cr1400}}\ \left(R^2 = 0.55\right) \quad (2)$$

where *a* and *b* are coefficients obtained from the linear regression analysis. Since no specific absorption feature can be directly related to the silt fraction, the latter was calculated subtracting the sum of the other two from 100. The difference and the corresponding estimates were compared to the measured values.

Figure 5 shows the continuum-removed spectra and reflectance curves (Fig. 5a) of soils with different clay content. There are differences in shapes of spectral curves, slopes, overall reflectance intensity, and position of absorption bands. The performance of the CR approach to predict soil texture is summarized in (Fig. 5b) for validation of the datasets. As can be observed, the CR approach allows obtaining a moderate-level performance only for clay prediction ($R^2 = 0.57$), characterized by RMSE values of 26.51 and 24.50 for the calibration and validation dataset, respectively.

4.2.4 Modeling Transformed Spectra (TS) of Soil Salinity

Soil salinity prediction in the VNIR-SWIR region can be better analyzed using second derivatives transformed spectra (TS_{cr}) (Fig. 6 and Table 4). The 34 soil sample spectra were divided into five salinity classes. In each class, an average spectrum was calculated to represent each soil salinity class (Fig. 6a,b). The plot shows that the reflectance curves display two deep absorption regions at 1,415 and 1,915 nm and several weak absorption regions near 494, 673, 1,748, 2,207, and 2,385 nm. The absorption region depth varies with the level of soil salinity. These features suggest that with increasing salinization, the soil moisture content increases.

Figure 6 demonstrates that the overall reflectance decreases between 589 and 803 nm as samples become more salinized due to an increase in the evaporate mineral content within the soil. The reflectance curves show a shoulder at around 803 nm and are similar to one another with nine distinct absorption features at 487, 671, 905, 1,144, 1,416–1,447, 1,800, 1,911–1,945, 2,203, and 2,345 nm. However, the depth of the absorption feature varies with the degree of soil salinization. As discussed in the literature, the absorptions at 671, 905, 1,144, and 1,800 nm were due to hydroxyl ions and water within the lattice of various hydrated evaporate minerals. Compared with wavelengths above, broader absorption features are found around 1,144 and 1,800 nm. The increases in absorption intensity at 671, 905, 1,144, 1,416–1,447, and 1,911–1,945 nm become more pronounced as salinity level increases.

The deeper water absorption features at around 1,416–1,447 and 1,911–1,945 nm are probably the combined results of O–H stretches and H–O–H bending

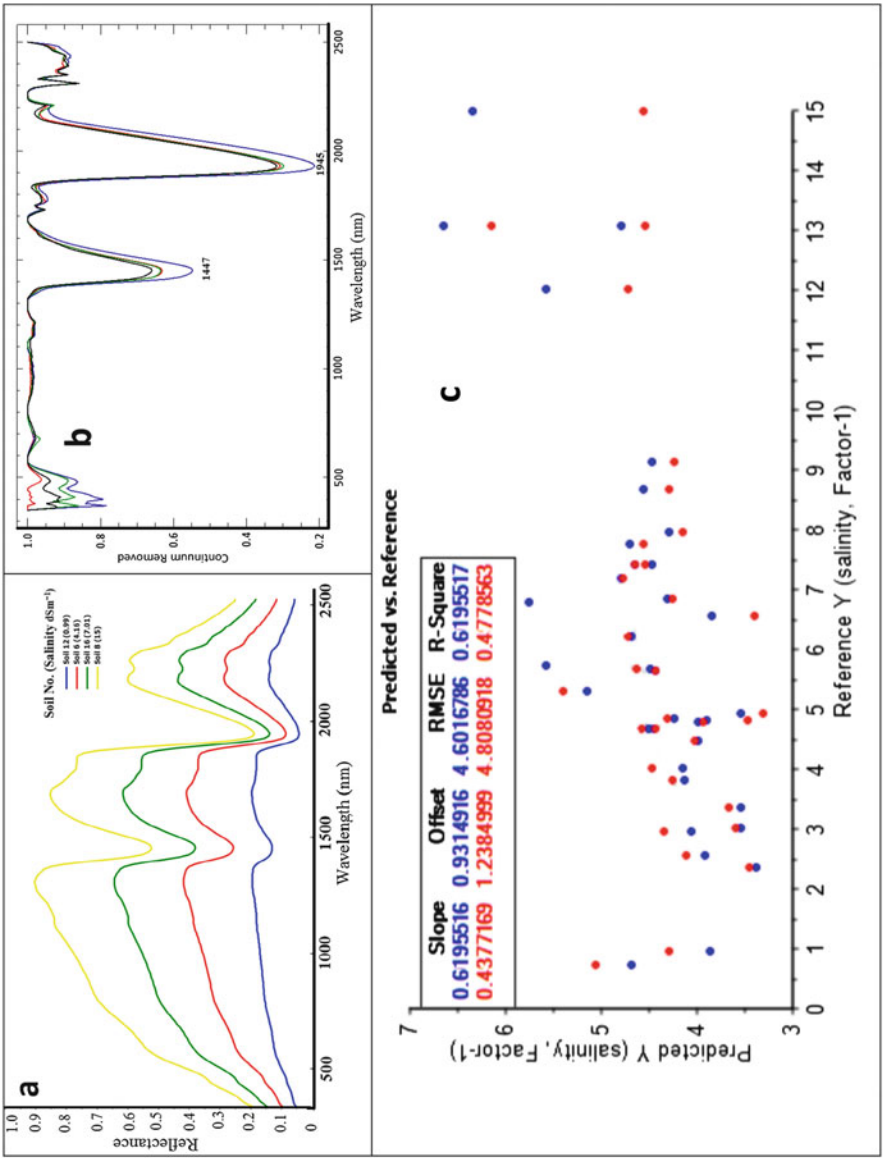

Fig. 6 Both the average spectra (**a**) and the CR (**b**) represented each soil salinity classes and measured vs. predicted soil salinity using the CR approach (**c**)

fundamentals and overtones, and the features become more extended and asymmetrical as salt contents increase. The position of the two absorption features at 1,416 and 1,911 nm moved to long wavelengths from 1,416 to 1,447 nm and from 1,911 to 1,945 nm with increasing salinization. Since, in this area, the salt composition was mainly highly hygroscopic salts like $MgCl_2$ salts, hygroscopic salts in air-dried soil samples could absorb water vapor from the environment. This leads to an increase in soil moisture. These results are consistent with Farifteh et al. [13].

As shown in Fig. 6, the low and nonsaline soils produced weak absorption features at 671, 905, and 1,144 nm. This phenomenon is reversed at around 1,800, 2,203, and 2,345 nm as spectral absorptions increase as soil salt contents decrease at these longer wavelength positions. The less salinized soil samples possess a well-defined, narrow, and deep hydroxyl feature at 2,203 nm. This phenomenon suggests the presence of well-crystallized clay minerals in soils [14]. The absorption intensity at 2,203 nm was reduced in the more salinized soils, which may be a result of the loss of crystallinity in the clay minerals. The absorption feature at 2,345 nm was weak, but distinct in asymmetrical form as the soil salt content decreases:

$$\text{Salinity}\ \left(\text{dSm}^{-1}\right) = 72.66 + 135.05 \times \text{TS}_{\text{CR }1431/1928}\ \left(R^2 = 0.62\right) \tag{3}$$

The performance of the CR approach to predict soil salinity is outlined in Fig. 6c for validation of the datasets. As can be observed, the CR approach allows obtaining a high-level performance for salinity prediction ($R^2 = 0.62$), characterized by RMSE values of 4.60 and 4.81 for the calibration and validation dataset, respectively. The ratio index (for the CR at 1,431 and 1,928 nm) compared with the difference and normalized indices might be the optimal index for soil salinity prediction because the bands at 1,431 and 1,928 nm are found in the NIR reflectance region, where the reflectance is primarily affected by the water content. The NIR band appears to be a good indicator of soil salinity. This result is in agreement with the findings of Farifteh et al. [13], Weng et al. [14], and Mashimbye et al. [20].

4.2.5 Modeling Spectra of Soil Organic Matter

The direct relation between reflectance values and OM content was investigated for each wavelength individually. The general reflectance pattern was investigated visually (Fig. 7) for the presence of absorption features in the reflectance from 1,600–1,800 nm (related to lignin) and 2,000–2,300 nm (related to cellulose, starch, and lignin).

Based on the reflectance pattern for wavelengths presented in Table 4, the highest correlation ($R^2 = 0.44$) between OM and reflectance is found using MSC followed by de-trending (Table 4), which is low. Also, highest correlation ($R^2 = 0.75$) between OM and reflectance is found in the visible range (640 and 690 nm), with a maximum around 600 nm and around the water absorption features (1,400 and 1,900 nm), and in the SWIR region (2,212 nm). This spectral region corresponds with the results reported by Bartholomeus et al. [32].

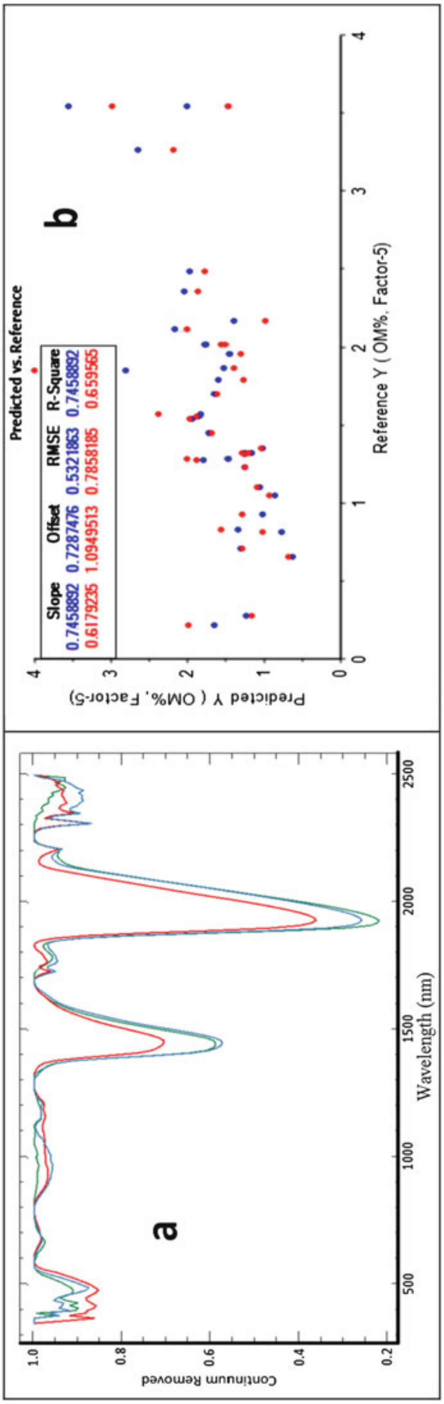

Fig. 7 Spectral signature in the range 1,600–1,800 nm and 2,000–2,300 nm part of the spectrum of three soils with a large range of organic matter content **(a)** and measured vs. predicted soil organic matter using the CR approach **(b)**

To select the most sensitive spectral bands to OM, the correlation coefficients between soil spectral reflectance and OM contents were calculated. The correlation was higher in the range of 500–700 nm. Thus, the OM content was estimated using a selection of spectra in the range of 500–700 nm.

The deviation of the arch (DOA)-based regression of the spectra at 600 nm is defined as the difference between the average reflectance value at 550 and 650 nm and the reflectance at 600 nm of each spectral curve [69]. The DOA reflects the concave or convex feature of the spectral curve in these bands. The variations in the DOA with OM are shown in Fig. 8. As the OM content increased, the DOA decreased; i.e., the soil spectral curve between 550 and 650 nm flattened [69]. Because the soil spectral curve between 550 and 650 nm was flattened, the estimation of OM contents was performed using a linear model.

The best calibration and validation results were obtained using the linear model, which yielded the highest R^2 (0.75) and the smallest RMSE (0.53):

$$\begin{aligned}\text{Soil organic matter }(\%) &= a \times \mathrm{TS}_{\mathrm{DOA600}} + b \\ &= 1.344 + 0.0197 \times \mathrm{TS}_{\mathrm{DOA600}}\ \left(R^2 = 0.53\right) \qquad (4)\end{aligned}$$

where $\mathrm{TS}_{\mathrm{DOA600}}$ is the deviation of the arch of the spectra at 600 nm and a and b are the model coefficients.

5 Overall Discussion

Sensing technology must be utilized to provide farmers with low-cost and rapid soil analysis in making farming more sustainable. Modern sensing technologies in agriculture have been given an important role for the improvement of agricultural productions, e.g., sustainable agriculture, to maintain food security. As agriculture is a major contributor to the increasing environmental destruction, change toward a more sustainable way of agriculture is urgent. Up-to-date information on soil properties is imperative for sustainable agricultural and environmental management. One of the cost-effective methods in soil analysis is the reflectance spectroscopy.

The use of VNIR-SWIR spectroscopy permitted the analysis of spectral properties of soils, which related to chemical, physical, or biological soil properties that might not have been revealed by conventional analyses and which had an influence on the parameter to be predicted. The choice of soil variables that were the focus of this study was partly guided by the goal of obtaining an integrative picture of key soil properties. It is worth noting that the visible range (350–760 nm) associated with soil color shows the huge influence on model accuracy, which is in line with other studies [11, 24]. The absorption feature in the range 350–1,000 nm might be due to the Fe oxides in the soil, mainly hematite and goethite [12]. Influential wavelengths located between 1,000 and 2,500 nm can be attributed to water, clay minerals, and organic matter [12].

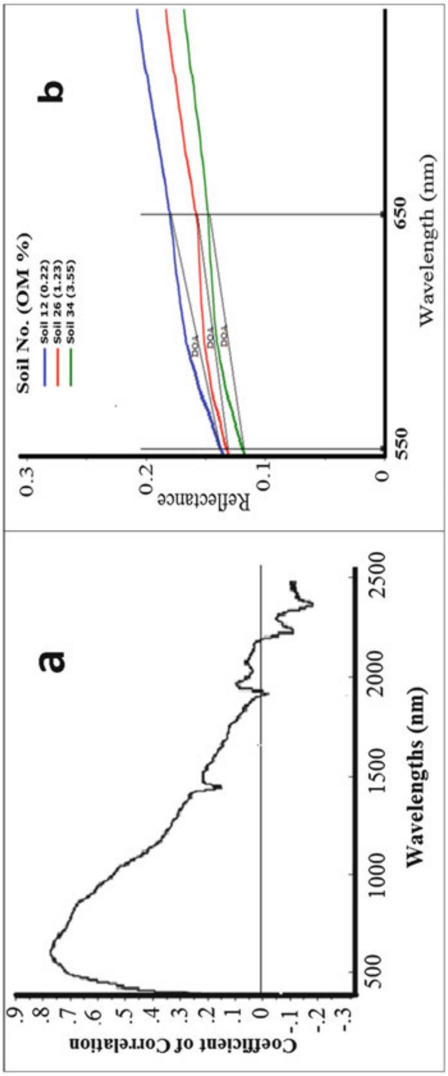

Fig. 8 (**a**) Coefficient of correlation between organic matter and soil spectral reflectance and (**b**) three distinct spectral curves at 500–700 nm showing the changes in the deviation of the arch (DOA) at 600 nm with soil organic matter (OM)

Correlation analysis between the reflectance and OM is critical for deciding the soil spectral bands mostly affected by OM. The spectral reflectance displayed the highest correlation with the OM content in the range of 500–700 nm. Zhang et al. [69] compared the correlations between the reflectance and OM of various soils. The results indicated that the reflectance in the range of 500–700 nm could be utilized to determine OM in many types of soils. Peng et al. [70] confirmed that the reflectance in the range of 570–630 nm is affected by OM, and the maximum correlation coefficient between them appears at 600 nm. Therefore, the deviation of the arch (DOA) of the spectra at 600 nm contains the majority of information regarding OM and can be used to estimate OM. As the OM content increased, the DOA gradually decreased. The intercept of the linear model of the DOA was 19.76, indicating that the DOA would be under 0 when the OM content was higher than 19.76 g kg^{-1}; i.e., the reflectance would decrease significantly because of the strong absorption by OM. Therefore, spectral features of other soil properties would be weakened due to the significantly decreased reflectance [70]. When OM content exceeded 19.76 g kg^{-1}, the OM played a dominant role in producing soil spectral features. Whereas when the OM content was less than 19.76 g kg^{-1}, it became less effective in masking out the spectral features of other soil properties.

6 Conclusions and Foresight for Decision Making

Concern about agricultural sustainability requires the development of modern technologies that do not have adverse effects on the environment, are effective for soil analyses, and lead to improvements in food productivity. This chapter has demonstrated that reflectance spectra contain much information and variation related to key soil parameters. Utilizing laboratory VNIR-SWIR spectroscopy good predictions can be achieved for some chemical and physical properties. The method allows the assessment of primary properties with direct spectral responses, which are directly affected by combinations and overtones of fundamental vibrations for organic functional groups and water, particle size, and surface properties of organic matter (OM), salinity, and clay minerals to have a direct spectral response in the VNIR-SWIR spectroscopy. In this context, it is possible to detect clay content, salinity, and OM with high accuracy. The pre-processing technique has been improved the prediction accuracy of a wide range of key soil properties. In the case of the clay content, the prediction capacity of the method proved to be high ($R^2 = 0.57$) using CR. The CR spectra yielded the best calibration models with respect to estimates of the soil salinity, which generated R^2 values of 0.62. The visible band is important for OM estimation using spectroscopy. The DOA at 600 nm is indicative of the convex and concave features of the spectral curves generated by OM and can be used for estimating OM. When the OM content exceeded 19.76 g kg^{-1}, the decreased reflectance due to the strong absorption by OM could mask the spectral features of other soil properties to a certain degree. VNIR-SWIR spectroscopy is a promising method for the fast prediction of key soil properties. Laboratory VNIR spectroscopy offers a low-cost solution for soil parameters monitoring, which could allow an increase in their spatial coverage and an increase in their sampling frequency. However, a critical research need in Egypt is the advancement of soil spectral libraries that will enhance the predictive ability of VNIR spectroscopy for soil quality attributes whatever the soil type.

The road ahead calls for using a point or image thermal spectrometer, which will enable obtaining more information that is spectral with better accuracy [71–73]. Decision makers are increasingly demanding fast, low-cost, easy-to-use, and nondestructive methods for monitoring changes in the physical and chemical characteristics of soil, water, and plants from the early stages of crop development until harvest. Therefore, the development of tools that farmers can use to evaluate efficiency at the farm level will open a new era for agricultural sustainability. Remote and proximal sensor tools have been used to monitor different aspects of agricultural production (e.g., fertilization, crop diseases, etc.). Most of these tools are characterized as nondestructive and noninvasive, and most of them are based on near-infrared (NIR) spectroscopy. Advances in NIR spectroscopy and chemometrics provide another possibility to traditional methods of conducting soil, water, and plant analyses [71–73].

Adapting and using modern technologies is a promising way to efficiently and reliably improve management farming practices, as well as to move toward the application of best management practices in the agricultural processes. Different studies have shown the important role of proximal sensors based on NIR spectroscopy in the analysis of crops. The use of NIR spectroscopy on agricultural harvesters has shown the potential to reduce the labor and expenditure required for the determination of relevant properties in different crops. Moreover, the availability of hyperspectral cameras has provided exciting new possibilities for online defect detection, which were not achievable with the use of sensors based only on the visible range of the electromagnetic spectrum (e.g., detection of defects in fruits). In addition, spectral imaging technologies, which acquire single or multiple images at selected wavelengths, might be used to detect specific quality attributes (pigments, sugar, starch, water, protein, etc.) in a wide range of crops and horticultural products. Finally, one of the potential advantages of using NIR spectroscopy for in-field crop monitoring is the analysis of fresh plant materials (e.g., leaf, whole plant) without the need for drying, grinding, or sending the sample to the lab. Various spectroscopic and imaging techniques have been evaluated for the detection of symptomatic and asymptomatic plant diseases.

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Part II
Integrated Natural Resources Management for Sustainable Production

Effect of Water Deficit on Food Productivity Under Saline Conditions: Case Study – North Sinai, Egypt

Mohamed Abu-hashim, Khaled Shaban, Amani Sallam, and Abdelazim Negm

Abstract Egypt is dependent mainly on the surface water coming from the Nile River. The water demand is increasing because of the rapid growth of populations and the impacts of climate change. Egypt is highly vulnerable to climate change, which increases the water demand and causes a loss of crops. Thus, one of the main challenges facing the sequential government during the previous decades was to enhance the agriculture sector by increasing the efficiency of water use. In this context, a field trial in Saline Soil at Sahl El-Tina (North Sinai) was designed in a system of a completely randomized block design and this trial was carried out during two winter seasons, 2011/2012 and 2012/2013, to study the response of economic crop (faba bean) yield to different water supply regimes. The experiment included three water irrigations, El-Salam Canal, schedules 3,600, 6,000, and 7,200 m^3/ha (ha = 10,000 m^2), and two varieties of faba bean. The results obtained showed a reduction in soil salinity values with increasing water supply. That is, applying the water regime of 7,200 m^3/ha revealed decreased soil salinity on the experimental farm by 30% compared with using the water regime 3,600 m^3/ha for both seasons. Nevertheless, the results of the yield quantity showed that the weight of seeds/plant (g) and plant height (cm) decreased with reduction of the water supply. For the yield quality, such as seed quality, carbohydrate percentage, high protein, seedling dry weight, and

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radical length were accompanied by low water application (3,600 m^3/ha). The results relevant to the approach to water use efficiency were suitable with lower water supplies. In addition, using the water regime of 6,000 m^3/ha with the Sakha 3 cultivar under saline soil conditions was more efficient according to the concepts of water saving, water use efficiency, seed quality, and yield.

Keywords Faba bean, Soil salinity, Water regime, Water stress, Water use efficiency

Contents

1 Introduction

1.1 Salinity Hazards

Salinity is considered to be one of the most extreme threats to irrigated agriculture in arid and semi-arid regions, and one-fifth of the irrigated land in the world consists of salt-affected soils. Approximately 1–2% of the arable land in these regions becomes unsuitable for cultivation yearly as a result of salinity and waterlogging [1]. Also, salinity had severe effects on biomass production, the relative growth rate, and the plant morphological parameters, such as the photosynthesis transpiration rate, and stomata conductance through the changes in the ionic status of applied water and in plant cells [2, 3]. The salinity of the soil water inhibits the plant growth for two reasons. First, the severe effect of salts that are produced in the soil solution, which could affect the ability of the plant to take up water already available; this could result in reducing the plant growth rate. The phenomenon is attributed to the osmotic pressure or the water deficit impact of salinity. Second, as the excessive amounts of salts enter the plant through the transpiration stream process, this leads to greater deterioration in plant photosynthesis processes, causing a reduction in plant growth rate and the subsequent injury of the plant cells in the transpiration leaves [4].

High salinity restricts the crop production and thus the agricultural sustainability. The depressive impact of soil salinity on the growth and development of plants results mainly in the bad physical condition of the soil and a physiological disturbance to plants [5, 6]. Nevertheless, under low salinity, the soil nutrient deficiency limits the plant growth more than the adverse effect of salinity, whereas under moderate and high salinity, the adverse effect of salinity is mainly responsible for retarding plant growth [7, 8]. Excessive soil salinity causes stunting of the growth of wheat and barley and reduces their leaf size, shoot length, and tillering [9]. Germination of wheat seed decreases with increasing soil salinity, and no germination occurs if soil salinity were above 30 dSm^{-1} [10]. Moreover, salinity reduced plant height and the number of tillers and the shoot and root dry weight of sorghum plants [11]. This phenomenon of saline stress resulted in decreasing the seed germination and growth rate of barley [12]. High salinity decreased the growth rate of barley and its biomass accumulation and reduced root hair density and root thickness. Under high salinity, sorghum growth was limited more than nutrient deficiency, and adding large amounts of fertilizers may cause more salinity and decrease plant growth [13].

There are several approaches to enhancing plant salinity tolerance, i.e. the chemical methods, the cultivation of salt-tolerant species, and the effective nutrient management plans in salt-affected soils. Plants require essential mineral nutrients during growth to grow and develop and produce a good yield. Nutrient management is considered one of the main factors and a vital component in the scientific package of recent agriculture technology. For instance, using potassium in doses lower than those recommended, the acquisition of K^+ could be considered as a result of the physiological similarities between Na^+ and K^+ [14]. The capacity of most plants to counteract the salinity hazards depends on the status of K^+ nutrition during the growth period. Also, potassium, as an essential nutrient to all plants and in most terrestrial plants as a major cationic inorganic nutrient, enhances several plant enzyme functions. Potassium contributes more than Na^+, Cl^-, and glycinebetaine in an osmotic adjustment under saline conditions and activates the crucial enzymatic reactions such as the formation of pyruvate. It is also a substantial contributor to the osmotic pressure of the vacuole and thereby maintains cell turgor [15].

1.2 Water Stress

Economic uses of water are considered a vital problem that could confront stakeholders such as agricultural companies and farmers, in addition to scientists in arid regions. The problem of water stress phenomena is becoming more acut, as the irrigated land in the world increases [16]. Identifying the optimal water demand and the time to apply it have limited the water supply to obtain the maximum yield with high-quality yield products. Otherwise, the shortage of water has caused a deterioration in most growth rates and the roles of mineral nutrition in plant growth, and the seed yield characteristics of broad bean plants [17]. A soil water deficit has led to a disturbance in the most physiological processes in plants and this in turn has resulted in a decrease in seed yield and quality [18]. Soil water deficits that could occur during the growth stage were considered to have the permanent adverse effect of salinity on the leaf area, branch number, and pod setting [19].

Water stress in arid and semi-arid regions is considered one of the main parameters affecting seed yield and quality, plant growth, and photosynthesis productivity. Ouda et al. [20] reported that 20% of the full water supply could be saved obtaining a yield reduction of 7%. However, Alderfasi and Alghamdi [21] mentioned that using an irrigation water supply with 75% of the soil water holding capacity resulted in an increased number of plant branches, plant height, number of pods/plant, and seed yield/ha. Moreover, Hirich et al. [22] showed that with half of the irrigation water supply, crop productivity was enhanced for the parameters of plant height, number of pods/plant, and seed yield/ha. Also, the water supply during vegetative growth using half of the water demand revealed a higher yield than by applying a full irrigation [23].

1.3 Faba Bean

One of the most important pulse crops in the arid regions in terms of popularity and seed protein content is the faba bean (*Vicia faba L.*). The total cultivated area in the world occupied by the faba bean was 4–7 M/ha [1]. The nutritional value of the faba bean was attributed to the high protein content, which ranged from 27% to 34%. Depending on their genotypes, the protein comprised three main components: globulins (79%), albumins (7%), and glutelins (6%) [24]. Under water shortage conditions and using the water deficit approach [25], the protein content of the faba bean yield increased, and these results compensated well for the data obtained by Alghamdi [26], Ibrahim and Kandil [27], and Al-Suhaibani [28], who described a decrease in yield associated with an increase in the soil water deficit. In addition, the carbohydrate percentage and high crude protein in seeds were relatively affected by low water levels applied during the growth period. However, the seed weight somehow showed a stable yield component of the faba bean under water stress treatments at different development stages. On the other hand, the seed quality of the faba was influenced by internal and/or environmental factors during seed development [29, 30]. Seed quality is measured by germination rate, percentage, and longevity [31, 32] and by the performance of the offspring. Seed germination and at the same time the early seedling were considered the most important phases for assessing any plant species. Thus, the seed tolerance to any stresses during the germination period should be considered and determined. The relationships between total yield dry matter, water loss rate, water use efficiency, and primary water content of the flag leaf were significant, and they could be attributed to the variation among the recommended cultivars [3]. Moreover, Ahmed [33] found that the water stress approach was pronounced to be more effective for the faba bean than the variation between the different varieties or salt stress. Within this context, El-Dakroury [34] revealed that increasing the irrigation doses from 60% to be 100% of actual evapotranspiration (ET), there was a significant increase in the growth criteria i.e., number of branches, plant height, leaf area, leaves and pods/plant, and dry weight of the total plant.

The objective of this investigation is to study the influence of water supply regimes on water use efficiency in arid regions, considering the impact of the water stress on the seed yield and the quality of the faba bean as the test crop under high saline soil conditions at North Sinai, Egypt.

2 Materials and Methods

A field trial was conducted on sandy loam soil in Sahl El-Tina, North Sinai Governorate, during two successive winter seasons, 2011/2012 and 2012/2013. The soil is mainly irrigated from the El-Salam canal, the main stream in this region, with an average salinity concentration, varying from 1.38 to 1.47 dSm^{-1}. The study area has a continental climate condition with hot summer and wet winter. The lowest temperature values were pronounced in January and February (22°C and 20°C), whereas the maximum rainfall amount is approximately 12.7 mm/month in February. The El-Salam canal, which is located at the northern Sinai, is considered to be one of the five mega-irrigation projects. The Egyptian Government was diverting part of the agricultural drainage water and conveying it to the newly reclaimed areas in Sinai after mixing the Nile water, the Damietta branch, in a ratio of 1:1 with the agriculture drainage water [35]. This strategy was used for the reclamation of 258,000 ha of land located along the Mediterranean coast of Sinai as a plan of the policymakers to extend horizontally into Sinai. The analyses of irrigation water (Table 1) were determined during the growing season, according to Cottenie et al. [37].

The experimental design during the two seasons was randomized complete block with three replications. We used two cultivars of the faba bean (Nobaria 1 and Sakha 3). Three water scenarios were applied: N1 "the normal irrigation by the local farmers in this region" (7,200 m^3/ha), L1 "irrigation water with 6,000 m^3/ha," and L2 "irrigation water with 3,600 m^3/ha." The irrigation regime was surface flow

Table 1 Salinity and the main macro/micronutrients content in irrigation water during faba bean planting in both seasons [36]

Treatments	Seasons	Water sampling periods				Mean
		November	January	March	April	
EC (dSm^{-1})	First	1.25	1.12	1.55	1.61	1.38
	Second	1.37	1.17	1.60	1.72	1.47
NO_3-N	First	12.23	14.49	17.31	22.20	16.56
	Second	14.66	19.96	19.23	22.58	19.11
NH_4-N	First	6.74	9.65	12.69	14.27	10.84
	Second	9.36	14.30	16.20	17.84	14.43
P	First	1.98	2.08	2.82	2.12	2.25
	Second	1.33	2.19	2.04	2.28	1.96
K	First	11.68	14.20	17.33	12.90	14.03
	Second	8.77	14.73	16.98	14.67	13.79
Fe	First	1.44	1.67	1.73	1.41	1.56
	Second	1.49	1.85	1.89	1.77	1.75
Mn	First	2.62	2.81	2.74	2.58	2.69
	Second	2.51	2.60	2.79	2.12	2.51
Zn	First	1.06	1.04	1.18	1.03	1.08
	Second	1.34	1.66	1.54	1.14	1.42

through pipelines, which was performed during the experiment, and was supplied with meter gauges that helped to control the amount of water to be used for irrigation. The region was distinguished by high salinity, and to overcome the salinity hazards during the germination that could affect and delay the sowing processes, we irrigated the soil for 4 h during the first day after sowing. During the second day, the soil was irrigated for 7 h, and then the irrigation regime was applied every 10 days. The characteristics of the soil under investigation are presented in (Table 2), and the analyses were prepared according to the standard methods of Page et al. [38].

During the maturing period, in the middle of May, the faba bean plants were harvested for both seasons. Plant samples were randomly taken to stimulate the weight of seeds/plant (g), plant height (cm), seed yield (Mg/ha), biological yield (Mg/ha), harvest index (%), and 100-seed weight (g) from each plot by using ten

Table 2 Physical and chemical properties in soil studied before planting [36]

Soil properties	Value
Particle size distribution [%]:	
Coarse sand	7.88
Fine sand	70.23
Silt	7.43
Clay	14.46
Texture class*	Sandy loam
Organic matter (g kg^{-1})	0.44
$CaCO_3$ (g kg^{-1})	6.90
EC, pH and soluble ions:	
EC (dSm^{-1}) (soil paste extract)	10.23
pH (soil suspension 1:2.5)	8.18
Soluble ions (mmol L^{-1})	
Na^+	79.64
K^+	0.93
Ca^{++}	8.83
Mg^{++}	12.90
Cl^-	70.00
HCO_3^-	5.33
SO_4^{2-}	26.97
Macronutrients and micronutrients [mg/kg]:	
N	45.00
P	4.25
K	178.00
Fe	1.39
Mn	3.43
Zn	0.81
Cu	0.13

*Texture is according to the United States Department of Agriculture triangle guarded plants. Water use efficiency (WUE) was computed according to Bos [39], and these computations were prepared depending on the above-ground biomass:

$$\text{WUE} = \text{seasonal biomass as dry matter/kg divided by seasonal water in ET.}$$
$$\text{ET} = \text{is equivalent dry land or rain-fed plot.}$$

The harvest index was determined by dividing the plant seed yield by the above-ground biomass. The seed quality parameters of the field experiments were identified using laboratory experiments at the Seed Technology Research Department, at the Agricultural Research Center, Egypt, during the two seasons. The germination percentage was determined by the percentage of normal seedlings according to the International Seed Testing Association (ISTA) [40]. Normal seedlings were also counted and expressed as the seed germination percentage. To measure the seedling dry weight, and the shoot and radical length (cm), ten normal seedlings from each replicate were prepared and counted according to Kirshasamy and Seshu [41].

The electrical conductivity (dSm^{-1}/mg) was measured to identify the seed quality. To do so, 25 seeds for each replicate were weighed and then soaked in 250 ml of de-ionized water for 24 h. The salinity of the seed leachate was determined according to the ISTA [40]. Moreover, the crude protein (%) in the seeds and the total carbohydrate percentages were determined according to the method of the Association of Official Agricultural Chemists [42].

3 Results and Discussion

The soil salinity results under different irrigation supply regimes in the two seasons during faba bean cultivars were collected from the soil surface layer after 4 days of water irrigation and are presented in Table 3. The obtained results showed that the lower soil salinity values were recorded from January to March compared with the values obtained in December and April for the same two seasons. These results could be attributed to the fact that the rainfall effect at North Sinai from January to March played an important role in decreasing the salinity at the soil surface compared with the other months. Also, by increasing the evaporation activity, increasing the water table level, and stopping the water supply, the values of soil salinity increased in May when the plants were harvested.

The results obtained were consistent with the finding of Ahmed [33], who showed that the soil salinity values increased as a result of high temperatures in North Sinai. Table 3 shows the effect of different irrigation supply scenarios on the soil salinity values during the two seasons. The irrigation supply with 7,200 m^3/ha revealed lower soil salinity of 3.30 dSm^{-1} in both seasons, whereas the other two water supply regimes showed soil salinity of 4.75 and 4.29 dSm^{-1} (6,000 m^3/ha), and 6.12 and 5.30 dSm^{-1} (3,600 m^3/ha) during the first and second seasons respectively. During the harvest period, increasing the water supply regimes in both seasons resulted in a decrease in the soil salinity. The irrigation with a water supply of

Table 3 Mean values of soil salinity after 4 days of irrigation water during faba bean planting [36]

	December		January		March		April		Mean		Harvest	
Irrigation	First	Second	First	Second	First	Second	First	Second	First	Second	First	Second
Salinity (dSm^{-1}) in the soil												
3,600	6.81	5.71	4.19	3.17	5.22	4.63	8.25	7.69	6.12	5.30	8.76	8.25
6,000	4.52	4.20	2.91	2.43	4.19	4.10	7.39	6.44	4.75	4.29	6.92	6.37
7,200	3.27	3.18	1.33	1.22	3.04	2.99	5.55	5.82	3.30	3.30	6.12	5.77

3,600 m^3/ha showed higher soil salinity values of 8.76 and 8.25 dSm^{-1} during the harvest time in the first and second seasons respectively, whereas the impact of the other two water supply regimes recorded that the soil salinity was 6.92 and 6.37 dSm^{-1} using the irrigation supply regime of 6,000 m^3/ha. Using the higher irrigation supply regime of 7,200 m^3/ha, the soil salinity was 6.12 and 5.77 dSm^{-1} during the first and second seasons respectively.

Table 4 presents the results of the yield parameters, i.e., the weight of the seeds/ plant (g), 100-seed weight (g), plant height (cm), and seed yield (Mg/ha) of the faba bean for the two varieties with the various water supply regimes. These results showed that the plants grown using irrigation regime N1 revealed higher values of these yield parameters compared with the L1 irrigation and L2 irrigation regimes. Also, the decreasing trend of these parameters was parallel with the increases in irrigation water intervals.

These results agree with the finding of Hirich et al. [22], who showed that a deficit irrigation approach during vegetative growth, with half the amount of the required water supply, revealed a higher yield than by adding the full irrigation. Otherwise, Balasio et al. [43] showed that the irrigation water intervals of 28 days during the vegetative stage revealed the highest grain yield.

The results in Table 5 show that the impact of the drought stress on yield parameters and the water supply regime imposed (N1, L1, and L2) induced a significant reduction in the biological yield (t/ha) by increasing the drought stress.

Table 4 Yield and yield components of the faba bean as affected by irrigation intervals for combined analysis as mean values for both seasons [36]

Irrigation	Varieties	Plant height (cm)	Weight of seeds/ plant (g)	100-seed weight (g)	Seed yield (Mg/ha)
N1 "normal irrigation"	Nubaria 1	82.00	152.20	109.20	3.57
	Sakha 3	77.30	145.90	98.70	3.93
Mean		79.60	149.00	104.00	3.75
L1 "late irrigation"	Nubaria 1	80.00	131.00	94.30	3.03
	Sakha 3	73.30	140.00	84.00	3.57
Mean		76.60	136.00	89.00	3.30
L2 "very late irrigation"	Nubaria 1	50.60	73.50	86.00	1.61
	Sakha 3	45.00	100.70	67.50	2.57
Mean		48.00	87.10	76.80	2.09
LS.D 5%					
I[a]		2.27	10.10	1.56	3.70
V[b]		4.85	8.26	3.91	1.70
I × V[c]		3.21	12.30	5.70	2.20
c.v		12.60	14.80	11.60	15.90

N1 "normal irrigation" (7,200 m^3/ha), L1 "late irrigation" (6,000 m^3/ha), and L2 "very late irrigation" (3,600 m^3/ha), *L.S.D.* Least Significant Difference, *c.v.* coefficient of variations

[a]Irrigation

[b]Varieties

[c]Interaction between the irrigation and the varieties

Table 5 The water deficit has an impact on some yield parameters of the faba bean in two sequential growing seasons (combined computation for the two seasons) [36]

Irrigation	Varieties	Biological yield (Mg/ha)	Harvest index (%)	Water use efficiency (kg/m^3)
N1, total applied water 7,200 m^3/ha	Nubaria 1	9.67	36.92	1.34
N1, total applied water 7,200 m^3/ha	Sakha 3	9.59	40.98	1.33
L1, total applied water 6,000 m^3/ha	Nubaria 1	8.09	37.45	1.35
L1, total applied water 6,000 m^3/ha	Sakha 3	8.90	40.11	1.48
L2, total applied water 3,600 m^3/ha	Nubaria 1	3.78	42.59	1.05
L2, total applied water 3,600 m^3/ha	Sakha 3	4.98	51.61	1.38

N1 "normal irrigation" (7,200 m^3/ha), L1 "late irrigation" (6,000 m^3/ha), and L2 "very late irrigation" (3,600 m^3/ha)

These results are in agreement with those of De Costa et al. [44], who mentioned that yield component analysis showed a positive yield response for irrigation water with an increase in the total biomass of the faba bean.

Moreover, the data in Table 5 show significant differences between irrigation regimes from the point of view of water use efficiency (WUE), and for the harvest index parameters. The results of the WUE showed that by using the water supply regime of 6,000 m^3/ha, it was 1.48 kg/m^3 for the cultivar Sakha 3 and it was higher than the other treatments by 1.34, 1.33, 1.35, 1.05, and 1.38 compared with the irrigation water supply with the different cultivars. Nevertheless, the water regime of 3,600 m^3/ha with Sakha 3 in Table 5 was more efficient than the other water regimes according to the water saving and the WUE concepts under the saline soil conditions. The harvest index was also influenced by the water regime, as shown in Table 5. These results are in parallel with the findings by Alireze and Farshad [3], Al-Suhaibani [28], and Link et al. [45].

The results displayed in Table 6 indicate that water treatments clearly affected the seed protein content. The increasing trend in seed protein content was in parallel with the water deficiency. This may be attributed to the fact that plants under higher water supply regimes (7,200 and/or 6,000 m^3/ha) had the lowest number of seeds/plants than those under the water supply regime of 3,600 m^3/ha. The results are consistent with the findings of Alghamadi [26] and Musallam et al. [46]. Also, the carbohydrate content of the faba bean indicated that the higher water regime (N1) showed lower values of carbohydrate content, whereas plants using the water regimes L1 and L2 had higher values of protein content and total seed carbohydrate.

These results are in agreement with the findings of Al-Suhaibani [28] and Liu and Andersen [47], who showed that the high crude protein values and carbohydrate percentage in seeds were affected by the low water supply. Also, Alghamdi [26],

Table 6 The chemical composition of the faba bean as affected by irrigation intervals for a combined analysis [36]

Irrigation	Varieties	Crude protein (%)	Carbohydrate (%)	Electrical conductivity (dSm^{-1}/mg)
N1, total applied water 7,200 m^3/ha	Nubaria 1	20.4	71.0	0.106
N1, total applied water 7,200 m^3/ha	Sakha 3	20.3	73.0	0.066
Mean		20.3	72.0	0.086
L1, total applied water 6,000 m^3/ha	Nubaria 1	21.5	72.2	0.095
L1, total applied water 6,000 m^3/ha	Sakha 3	21.8	73.5	0.052
Mean		21.6	72.8	0.073
L2, total applied water 3,600 m^3/ha	Nubaria 1	23.7	72.4	0.134
L2, total applied water 3,600 m^3/ha	Sakha 3	24.2	73.8	0.055
Mean		23.9	73.0	0.095
LS.D 5%				
I[a]		0.32	0.43	4.80
V[b]		0.42	0.53	5.40
I × V[c]		0.12	n.s	7.60
c.v		1.72	0.32	5.30

N1 "normal irrigation" (7,200 m^3/ha), L1 "late irrigation" (6,000 m^3/ha), and L2 "very late irrigation" (3,600 m^3/ha)

[a]Irrigation

[b]Varieties

[c]Interaction between the irrigation and the varieties

Ibrahim and Kandil [27], and Ahmed et al. [48] stated that the water stress increased the seed protein percentage and its electrical conductivity.

Data manifested in Table 7 show the impact of the water supply regimes on fresh and dry seedling weight, shoots, and radical length, and the germination percentage of the two varieties. These results showed that using the normal water supply regime (L1) increased the germination percentage by 90% compared with water supply regimes N1 and N2 by 84% and 80.0% respectively. The finding was true that under saline conditions the faba bean seeds cannot tolerate water stress that could be the result of increasing the irrigation intervals up to 21 days.

The seed germination percentage of the Sakha 3 cultivar was higher than that of the Nobaria 1 cultivar under irrigation water treatments. Also, the highest values of seed germination were 92% for the Sakha 3 cultivar under the irrigation water supply regime N1, whereas the lowest value of 79% was obtained using the Nobaria 1 cultivar using the L2 water supply regime.

To support the above results, Fig. 1 presents sample results for faba bean plant growth under saline conditions. Figure 1a shows seedbed preparation before

Table 7 Vigor test of the faba bean as affected by water regimes for combined analysis [36]

Irrigation	Varieties	Germination (%)	Shoot length (cm)	Radical length (cm)	Fresh weight (g)	Dry weight (g)
N1 "normal irrigation"	Nobaria 1	88.0	15.7	9.7	2.5	0.20
	Sakha 3	92.0	16.0	9.3	2.3	0.22
Mean		90.0	15.8	9.5	2.4	0.21
L1 "late irrigation"	Nobaria 1	82.0	13.3	12.5	2.2	0.23
	Sakha 3	86.0	12.5	13.3	2.0	0.25
Mean		84.0	12.9	12.9	2.1	0.24
L2 "very late irrigation"	Nobaria 1	79.0	11.5	13.5	2.0	0.30
	Sakha 3	82.0	11.4	12.8	1.9	0.32
Mean		80.0	11.4	13.1	1.9	0.31
LS.D 5%						
I[a]		n.s	n.s	n.s	0.6	0.30
V[b]		2.3	0.48	0.27	n.s	0.20
I × V[c]		n.s	n.s	0.34	1.12	0.58
c.v		1.27	1.63	0.93	2.28	5.6

N1 "normal irrigation" (7,200 m^3/ha), L1 "late irrigation" (6,000 m^3/ha), and L2 "very late irrigation" (3,600 m^3/ha)
[a]Irrigation
[b]Varieties
[c]Interaction between the irrigation and varieties

planting, whereas Fig. 1b presents the sowing and treatment process. Figure 1c shows the plant growth under irrigation water with a rate of 3,600 m^3/ha, whereas Fig. 1d presents the same for an irrigation water rate of 6,000 m^3/ha. Similarly, Fig. 1e shows faba bean growth under an irrigation water rate equal to 7,200 m^3/ha for the plot unit and Fig. 1f indicates the planting of the Sakha 3 faba beans with an irrigation water rate of 7,200 m^3/ha for the plot unit and planting Nubaria 1 faba beans.

4 Conclusion and Recommendations

The water stress regimes in this study revealed a decline in soil salinity values with increasing irrigation water supply regimes. The yield and yield component parameters decreased significantly with decreasing water supply regimes under the saline soil conditions. In addition, salinity had its main effects on biomass production, the relative growth rate, and the morphological plant parameters, such as the photosynthesis transpiration rate, and stomata conductance through the changes in the ionic status of applied water and in plant cells.

The accurate use of water is considered the vital problem that could confront stakeholders such as agricultural companies and farmers in addition to scientists in arid regions. Also, the problem of water stress phenomena is becoming more acute as

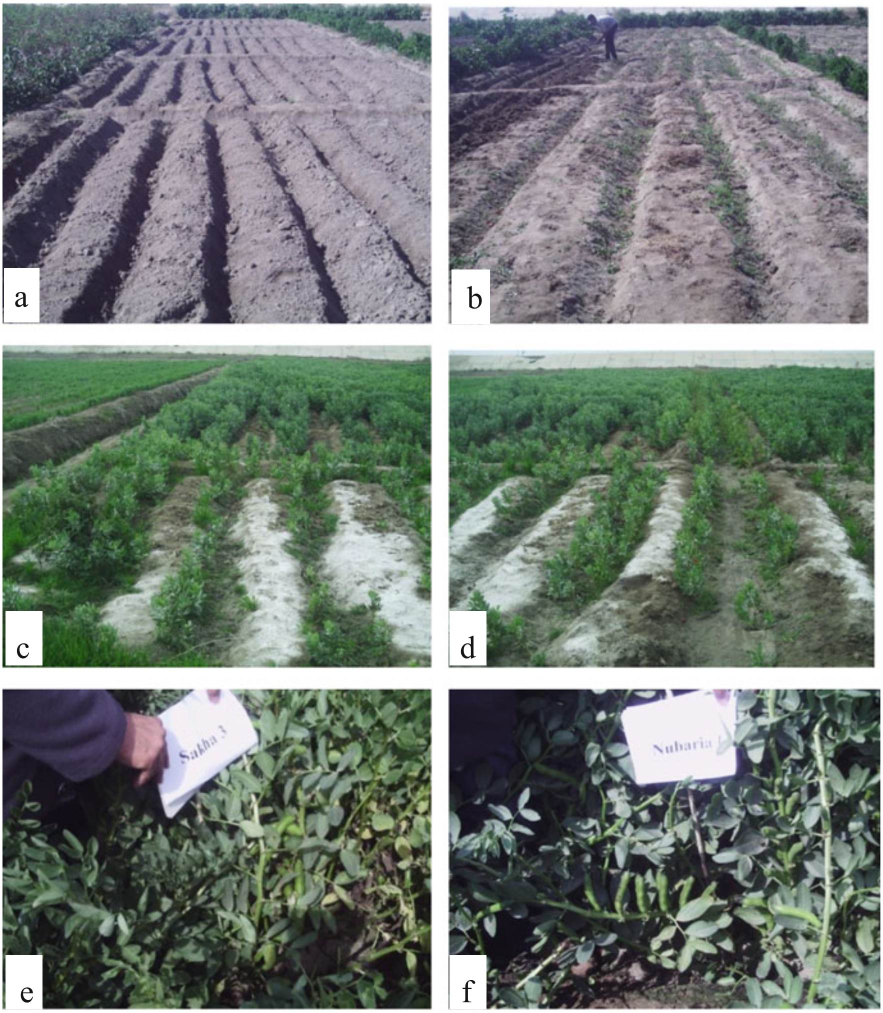

Fig. 1 Growth of faba bean plants under saline conditions. (**a**) Seedbed preparation before planting. (**b**) Sowing and treatment process. (**c**) Irrigation water at a rate of 3,600 m^3/ha. (**d**) Irrigation water at a rate of 6,000 m^3/ha. (**e**) Irrigation water by rate 7,200 m^3/ha for plot unit and planting faba bean Sakha-3. (**f**) Irrigation water by rate 7,200 m^3/ha for plot unit and planting faba bean Nubaria-1

the irrigated land in the world increases. Identifying the optimal water demand and the time to apply it limited the water supply to obtain the maximum yield with high-quality yield products.

For the North Sinai region, applying the irrigation water scenario of 7,200 m^3/ha resulted in a decrease in the salinity of 30% in soils compared with the irrigation water regime of 3,600 m^3/ha. Moreover, seed germination percentages were significantly decreased under a lower irrigation water supply than with normal irrigation, whereas seedling dry weight and radical length were increased with the lowest water supply (3,600 m^3/ha). Also, the carbohydrate percentage and high protein in seeds were pronounced with a low water supply. The water stress using the water supply of 3,600 m^3/ha using the Sakha 3 cultivar was more efficient under saline soil conditions according to the WUE approach and water saving.

These varieties with the recommended water supply regimes could be used to compensate for the normal water supply treatments in North Sinai to reduce the amount of the water supply under saline soil.

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Land, Air, and Water Resources on Sustainable Agricultural Development in Egypt

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Abstract The experiments were carried out at Moshtohor, Kalubia governorate (latitude, 30° 21′N; longitude, 31° 14′E; and elevation, 14 m), during 2015/2016 growing seasons to test model application of wheat under Egyptian conditions. A computer application program has been developed as Consumptive Use Program plus (CUP plus) as it is an application that can estimate crop evapotranspiration (ETc) and evapotranspiration of applied water (ETaw). The program uses daily and monthly measured weather data to estimate daily soil water balances for surfaces that account for evapotranspiration losses and water contributions from rainfall, seepage, and irrigation. Soil water-holding characteristics, effective rooting depths, and irrigation frequency were measured with rainfall and ETc data to calculate a daily water balance and determine rainfall and ETaw, which is equal to the seasonal cumulative ETc minus the effective rainfall. The main objective of this paper research is testing a mode for determining reference evapotranspiration (ETo), crop coefficient (Kc) values, crop evapotranspiration (ETc), and evapotranspiration of applied water (ETaw), which provides an estimate of the net irrigation water diversion needed to produce a crop. The obtained results show that ETo arrives to the maximum in May by 188.19 mm/month, but ETaw arrives at the maximum in April by 110.71 mm/month. The application outputs and includes a wide range of tables and charts that are useful for irrigation planning and decision-making.

Keywords Climate data, Crop coefficient, Evapotranspiration, Program, Water balance

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Contents

1 Introduction

The hydrologic cycle (water cycle) is the continuous movement of water on, above, and below the surface of the earth. The water cycle is also essential for the maintenance of most life and ecosystems on the planet.

"Evapotranspiration (ET) is the loss of water to the atmosphere by the combined processes of evaporation (from soil and plant surfaces) and transpiration (from plant tissues)" (http://wwwcimis.water.ca.gov/Resources.aspx). It is an indicator of how much water your crops, lawn, garden, and trees need for healthy growth and productivity. Accurate estimates of ET are needed in many circumstances. In agricultural irrigation, for example, estimates of ET are necessary for irrigation scheduling, water transfers, planning, and other water issues. For ET to take place, the following conditions have to be met. First, water has to be present at the surface. Second, there must be some form of energy to convert the liquid water into a water vapor (http://wwwcimis.water.ca.gov/Resources.aspx). Third, the water vapor goes away from the evaporating surface. Precipitation and irrigation are the two primary sources of water that plants use. Plant leaves and soil surfaces temporarily retain some part of the water applied to the field; this part is readily available for evaporation. The remaining part infiltrates into the soil. Plants extract the infiltrated water through their roots and transport it up to their leaves for photosynthesis, a process by which plants produce glucose (sugar). In addition to water, plants also need carbon dioxide and light for photosynthesis. The light comes from the sun and CO_2 comes from the atmosphere. In order to take in CO_2 from the atmosphere, plants open their stomata, the microscopic pores on plant leaf surfaces. It is during this process that they lose their water to the atmosphere. The conversion of liquid water into water vapor requires large amounts of energy (about 540 calories per gram of water at a temperature of 100°C). This energy is provided by the sun in the form of solar energy. The solar energy is absorbed by water molecules and converted to latent heat energy, the energy that is tied up in vapor molecules. The water vapor thus produced escapes to the atmosphere because of a vapor pressure gradient between the surface and atmosphere. Once in the atmosphere, it is taken further away from the surface by the wind (or other mechanisms), creating more gradient between the evaporating surface and the air above it. This process continues as long as the three conditions mentioned above are present. There are many factors affecting the estimation of ET: weather parameters (air temperature, solar radiation, relative humidity, wind speed, and others), soil factors (soil structure, texture, density, and chemistry), and plant factors (plant type, root depth and foliar density, height, and stage of growth). ET can be measured by lysimeters, estimating ET using analytical and empirical equations, but lysimeters are expensive. Reference ET is the ET rate of a reference crop expressed in millimeters. The American Society of Civil Engineers (ASCE) recommends the use of ETos and ETrs, respectively, where "s" stands for standardized surface conditions. Crop factor, commonly known as crop coefficient (Kc), is used to calculate the actual evapotranspiration (ETc).

"There are many theoretical and empirical equations around the world to estimate ETo. The choice of any one method depends on the accuracy of the equation under a given condition and the availability of the required data. For reference surfaces with known biophysical properties, the main factors affecting ETo include solar radiation, relative humidity, vapor pressure, air temperature, and wind speed" (http://wwwcimis.water.ca.gov/Resources.aspx).

The Egyptian agriculture is facing water shortage problem; this will need to improve irrigation techniques.

Consumptive Use Program plus (CUP plus) is a user-friendly Microsoft Excel application program. The program was developed to help growers and water agencies determine reference evapotranspiration (ETo), crop coefficient (Kc) values, crop evapotranspiration (ETc), and evapotranspiration of applied water (ETaw), which provides an estimate of the net irrigation water diversion needed to produce a crop [1]. The program also can be used to study the impact of climate change on evapotranspiration and irrigation water needs. CUP plus computes reference evapotranspiration (ETo) from "daily solar radiation, maximum and minimum temperature, dew point temperature, and wind speed using the daily Penman-Monteith equation. The program uses a curve fitting technique to derive one year of daily weather data from the monthly data and to estimate daily ETo" (http://www.water.ca.gov/waterplan/docs/cwpu2013/Final/vol4/crop_water_use/06CUP_). The program uses daily rainfall data to estimate bare soil evaporation as a function of the mean of ETo and wetting frequency in days. A bare soil Kc value is calculated to estimate the off-season evapotranspiration and as a baseline for in-season Kc calculations. Further, the program computes and applies all ETo and Kc values on a daily basis to determine crop water requirements by month, by season, and by year. The program outputs a wide range of tables and charts that are useful for irrigation planning. Snyder et al. [2] reported that, while evapotranspiration rates are known to increase with higher temperature, other factors in addition to rising temperatures also affect evapotranspiration (ET). For example, increasing humidity and higher CO_2 concentrations both tend to reduce transpiration and counteract the higher temperature effects on ET. Ghandour et al. [3] discussed a simple method to convert between reference evapotranspiration for short canopies (ETo) and tall canopies (ETr) using a modified Penman-Monteith equation and between the corresponding Kco and Kcr factors. Using weather data from 49 stations in California in a wide range of climates, a good relationship was found between the slope of monthly mean ETr versus ETo rates and the mean daily ETo rate for July. Similarly, a good relationship was found between the slope of monthly mean ETo versus ETr rates and the mean daily ETr rate for July. The slopes of regressions of daily ETr versus ETo rates and daily ETo versus ETr rates through the origin were nearly identical to slopes based on monthly calculations. The relationships can be used to estimate ETr from ETo and vice versa and to make crop coefficient conversions between the two reference evapotranspiration surfaces. Nassar et al. [4] concluded that no deterioration in soil productivity with a good yield was observed when a good management of proper land, water, and crop under saline irrigation practices was established. Ghandour [5] used the model for simulation of evapotranspiration of applied water (SIMETAW) to determine effective rainfall and evapotranspiration of applied water (ETaw) for crop and land-use categories, which include similar agricultural crops and other surfaces, by different regions having similar ETo rates within California and Egypt Delta. The model uses daily observed or simulated climate data to account for ET losses and water contributions from seepage of groundwater, rainfall, and irrigation on a daily basis over the period of record to simulate a daily water balance. The model can use daily climate data or daily climate data simulated from monthly data to estimate daily ETo. Bandyopadhyay and Mallick [6] indicated a constant decrease in soil water flux with increasing irrigation frequencies or rainfall with a concomitant increase in the actual evapotranspiration. By using water balance method, the seasonal evapotranspiration with four post sowing irrigations amounted to 250 mm with zero groundwater contribution; the crop coefficient values estimated for wheat can be used to work out crop water requirements and also irrigation scheduling under similar climatic conditions. French et al. [7] reported from modeling the surface energy balance using observations of canopy radiometric surface temperatures, readily available meteorological data, and nadir-view photography, which showed agreement within 1.1 mm day^{-1} of independently obtained ET observations based on soil water depletions. This shows that energy balance modeling is a feasible and potentially valuable method for scheduling irrigations in arid environments. The experiment also showed that seed and oil yield were weakly correlated with ET for seasonal water supplied between 250 and 290 mm. Pereira et al. [8] said that crop coefficient reference ET method is a robust method that provides for straightforward, visually-based derivation and application of the Kc curves over a wide range of climates and locations. The dual Kc method of FAO56 enables the estimation of impacts of surface wetting by precipitation and irrigation on evaporation from soil and the total ET rate, especially during vegetation development and also during periods of dormant vegetation growth such as during winter in extreme latitudes. Although simple in design and construction, the Kc method successfully incorporates a number of consistent and compensating factors that distinguish the ET of any unique crop from that of the reference ET. This characteristic has attracted a broad range and a large number of users, whose backgrounds range from nonscientific commercial and operations-oriented users to relatively sophisticated research users who require high accuracy in estimates. Anderson et al. [9] analyzed three eddy covariance (EC) sites in two contrasting agricultural systems to demonstrate how a flux-variance-based partitioning algorithm can be used to partition evapotranspiration into basal, soil evaporation, and stress coefficients for determination of agricultural water consumption. The objectives of this study were as follows: to improve ETc accuracy, to improve the dissemination of Kc and crop evapotranspiration (ETc) information to growers and water purveyors, and to compute and apply all ETo and Kc values on a daily basis to determine crop water requirements by day, by month, by season, and by year, using a free model (CUP plus) for determining reference evapotranspiration (ETo), crop coefficient (Kc) values, crop evapotranspiration (ETc), and evapotranspiration of applied water (ETaw), which provides an estimate of the net irrigation water diversion needed to produce a crop.

2 Materials and Methods

The experiments were carried out at Moshtohor, Kalubia governorate (latitude, 30° 21′N; longitude, 31° 14′E; and elevation, 14 m), during 2015/2016 growing seasons to test CUP plus model application of wheat under Egyptian conditions.

This worksheet, CUP plus program, has been developed and created by California Department of Water Resources and Department Land, Air and Water Resources, University of California, USA (https://www.fws.gov/lodi/).

Reference evapotranspiration (ETo) is estimated from daily weather data using a modified version of the Penman-Monteith (PM) equation as in Allen et al. [10, 11]. The equation is:

$$\mathrm{ET_{ref}} = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{C_n}{T+273}\,u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)} \quad (1)$$

where Δ is the slope of the saturation vapor pressure as a function of the mean daily air temperature curve (kPa °C^{-1}), R_n and G are the net radiation and soil heat flux density in MJ m^{-2} day^{-1}, γ is the psychometric constant (kPa °C^{-1}), T is the daily mean temperature (°C), u_2 is the mean wind speed in ms^{-1}, e_s is the saturation vapor pressure (kPa) calculated from the mean air temperature (°C) for the day, and e_a is the actual vapor pressure (kPa) calculated from the mean dew point temperature (°C) for the day.

The coefficient 0.408 converts the R_n − G term from MJ m^{-2} day^{-1} to mm day^{-1}, and the coefficient $C_n = 900$ combines together several constants and coverts units of the aerodynamic component to mm day^{-1}.

The product 0.34 u_2, in the denominator, is an estimate of the ratio of the 0.12 m tall canopy surface resistance (r_c = 70 sm^{-1}) to the aerodynamic resistance ($r_a = 205/u_2$ sm^{-1}).

"It is assumed that the temperature, humidity and wind speed are measured between 1.5 and 2.0 m above the grass-covered soil surface" (http://www.water.ca.gov/waterplan/docs/cwpu2013/Final/vol4/crop_water_use/06CUP_).

If only temperature data are available, then CUP plus calculates ETo using the Hargreaves-Samani (HS) equation [12, 13]:

$$\text{ETo} = 0.0023\ (\text{Tc} + 17.8)\ R_a\ (\text{Td})^{1/2} \tag{2}$$

where Tc is the monthly mean temperature (°C), R_a is the extraterrestrial solar radiation expressed in mm/month, and Td is the difference between the mean minimum and mean maximum temperatures for the month (°C).

The calculation of extraterrestrial radiation and other parameters in the Penman-Monteith and Hargreaves-Samani equations are described in Allen et al. [10, 11].

If pan data are used in CUP plus, then the application automatically estimates daily ETo rates using a fetched value (i.e., an upwind distance of grass around the pan). The new method in the CUP plus estimates ETo from Epan data without the need for wind speed and relative humidity data.

2.1 *Crop Coefficients and Evapotranspiration*

Field and row crop Kc values are calculated using a method similar to that described by Doorenbos and Pruitt [14] and Allen et al. [11]. A generalized curve is shown in Fig. 1. In their method, the season is separated into initial (date A–B), rapid (date B–C), midseason (date C–D), and late season (date D–E) growth periods. Kc values are

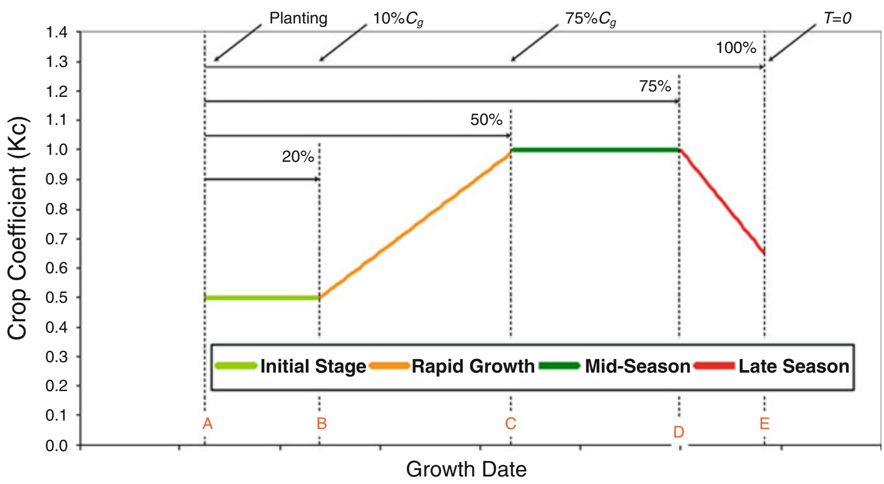


Fig. 1 Hypothetical crop coefficient (Kc) curve for typical field and row crops showing growth stages and percentages of the season from planting to critical growth dates

denoted as KcA, KcB, KcC, KcD, and KcE at the end of the A, B, C, D, and E growth dates, respectively.

During the initial growth, the Kc values are at a constant value:

KcA = KcB (http://www.water.ca.gov/waterplan/docs/cwpu2013/Final/vol4/crop_water_use/06CUP_).

In the rapid growth period, the canopy increases from about 10 to 75% ground cover; the Kc value increases linearly from KcB to KcC. The Kc values are also at a constant value during midseason, so KcC = KcD. During late season, the Kc values decrease linearly from KcD to KcE at the end of the season.

2.2 Description of Analytical Tools

Estimation of daily crop coefficients (Kc) and crop evapotranspiration (ETc) main features and capabilities:

- CUP plus is written with Excel software.
- Calculate daily ETo from the daily Penman-Monteith equation.
- Employ the latest methodology to determine crop coefficients for different crops.
- Calculate daily crop coefficients and crop evapotranspiration.
- Adjust crop coefficients.
- Output 1 year of daily weather, Kc, ETc, and ETo data for the current weather information.
- Provide daily Kc and monthly total values of ETo, ETc, and rainfall.
- Provide a bar graph of monthly total values of ETo and ETc for the crop information.
- The input data, crop name, planting date, ending date, and initial growth wetting frequency, are considered.
- The weather data consist of R_s, Tmax, Tmin, wind speed, Tdew, and rainfall (Fig. 2).

2.3 The SIMETAW Program

The SIMETAW program generates daily weather data from daily mean climate data by month. This allows for the simulation of daily weather data where only monthly means exist, which is "a good tool for filling missing data points. In addition, the simulation program is useful for studying the effects of climate change" (https://dspace.library.colostate.edu/bitstream/handle/10217/46454/122_Proceeding). All of the ETaw calculations are done on a daily basis, so the estimation of effective rainfall and, hence, ETaw is greatly improved over earlier methods. In addition, the use of the widely adopted Penman-Monteith equation for reference evapotranspiration

Fig. 2 Interface of monthly climate input worksheet

(ETo) and improved methodology to apply crop coefficients for estimating crop evapotranspiration is used to improve ETaw accuracy (http://www.dwr.water.ca.gov/pubs/planning/california_water_plan_2005_update__bul).

The application uses the daily climate data, i.e., maximum (Tx) and minimum (Tn) temperature and precipitation (Pcp).

The application uses daily weather data to determine reference evapotranspiration (ETo), using the Hargreaves-Samani (HS) equation [10, 11].

The SIMETAW program can "generate daily weather data from monthly mean values for use in studying climate change scenarios and their possible impacts on water demand" (https://www.sciencedirect.com/science/article/pii/S209531191360742X).

3 Results and Discussion

3.1 *Reference Evapotranspiration (ETo) Curve During Wheat Growing Season*

After data entry, the CUP plus program also plots daily calculated reference evapotranspiration (ETo) with different colored lines for each growth period during the season (Fig. 3).

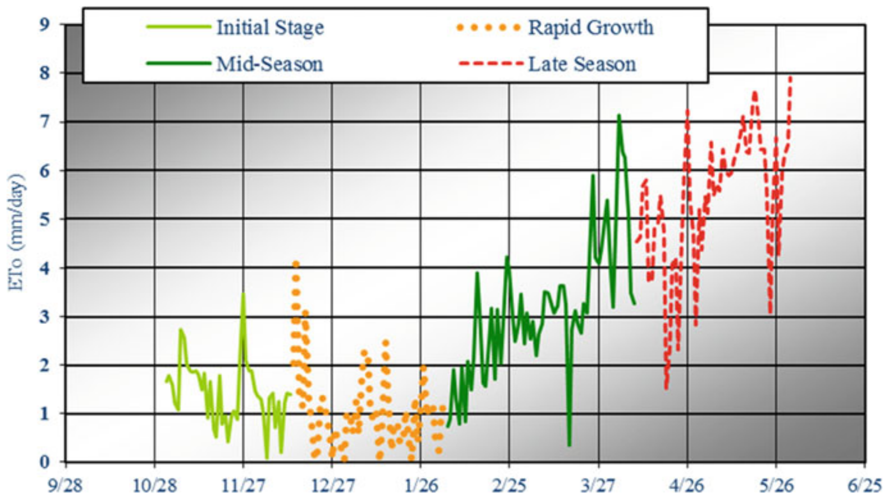


Fig. 3 Reference evapotranspiration (ETo) curve during wheat growing season

Reference evapotranspiration (ETo) curve during wheat growing season of daily weather data including calculated reference evapotranspiration (ETo) from weather data.

The reference evapotranspiration (ETo) curve start fluctuates increasing from the initial stage, rapid growth and midseason to arrive at the maximum in late season (May).

3.2 *Evapotranspiration of Applied Water (ETaw) and Crop Evapotranspiration (ETc)*

For one year of daily calculated crop coefficients and crop evapotranspiration for the current crop (wheat), the crop evapotranspiration (ETc) and evapotranspiration of applied water (ETaw) values were calculated as shown in Fig. 4.

The crop evapotranspiration (ETc) curve fluctuates until arriving at the maximum between March and April. Evapotranspiration of applied water (ETaw) curve starts increasing from December to arrive the maximum between March and April.

3.3 *Daily Calculated Bare Soil and Crop Coefficient (Kc) Values*

The CUP plus program plots daily calculated bare soil and crop coefficient (Kc) values with different colored lines for each growth period for currently entered

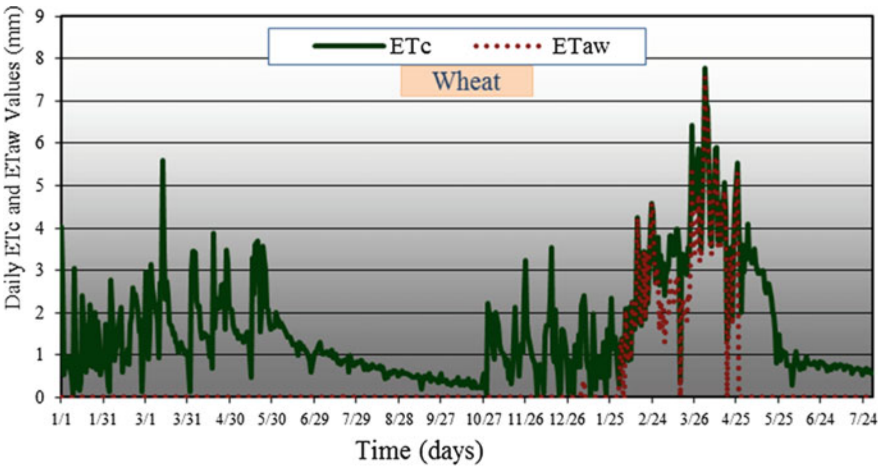


Fig. 4 Daily ETc and ETaw versus time

daily weather and crop – soil information during the growing season and off-season. Then it uses the baseline to determine crop coefficients (Kc) during the initial growth periods. During the off-season and initial growth period, soil evaporation is the main component of evapotranspiration ET. Therefore, CUP plus uses a two-stage soil evaporation model for estimating bare soil coefficients as a function of mean reference evapotranspiration (ETo) and wetting frequency in days from rainfall or irrigation.

The colored line in (Fig. 5) shows a crop coefficient (Kc) curve for a crop that had frequent irrigation between planting that increased the Kc value during the initial growth. The bare soil Kc (dark line) was higher than the crop Kc (dot colored line) during part of the season. In all cases, the higher of the bare soil and crop Kc is used to determine the crop evapotranspiration (ETc) on each day. The Kc values for the wheat have been adjusted for wetting frequency from irrigation and rainfall during that period.

3.4 Cumulative Daily Evapotranspiration of Applied Water (ETaw) Values with the Cumulative Net Application (NA)

Evapotranspiration of applied water (ETaw) is the sum of the net irrigation applications to a crop during its growing season, where each net irrigation application (NA) is equal to the product of the gross application (GA) and an application efficiency fraction (AE), "(NA $=$ GA $\times$ AE). The gross application is equivalent to the applied water, and the application efficiency is the fraction of GA that

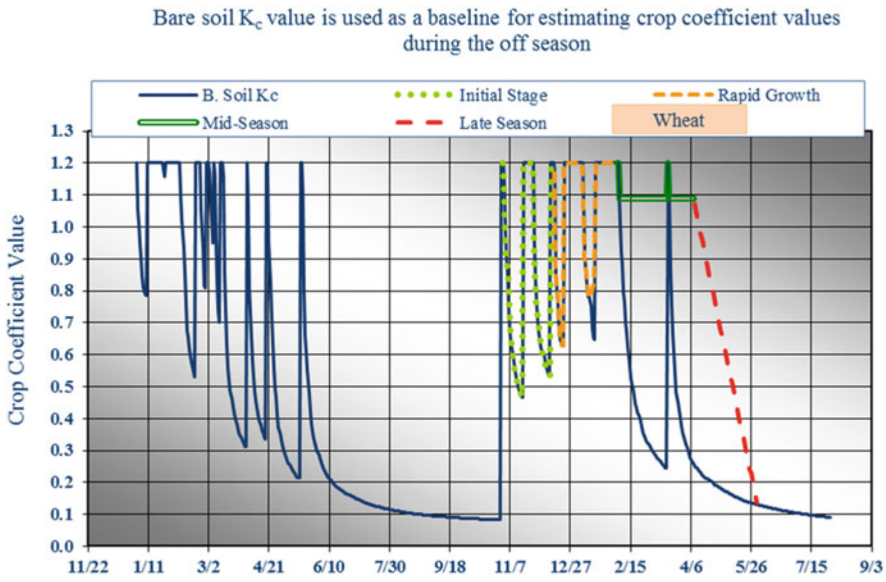


Fig. 5 Daily calculated bare soil and crop coefficient values with different colored lines for each growth period for currently entered daily weather and crop/soil information during the growing season and off-season

contributes to crop evapotranspiration (ETc)" (http://www.water.ca.gov/waterplan/docs/cwpu2013/Final/vol4/crop_water_use/06CUP_).

Evapotranspiration of applied water "(ETaw) can be calculated as the daily evapotranspiration (DETc) minus the estimated daily effective seepage contribution (DEspg) minus the daily estimated effective rainfall contribution (DEr) minus the difference in soil water content (DWC) from the beginning to the end of the season. The figure below shows the comparison of the cumulative daily evapotranspiration of applied water (ETaw) values with the cumulative net application (Cum. NA) for wheat over the period" (http://www.water.ca.gov/waterplan/docs/cwpu2013/Final/vol4/crop_water_use/06CUP_) as shown in Fig. 6).

3.5 Soil Water Balance (WB)

The Consumptive Use Program plus program also can plot daily calculated water balance (WB) for crops using daily weather data. In Fig. 7 the plot shows fluctuations in soil water content between field capacity and the maximum depletion during the off-season. And also there are fluctuations between field capacity and maximum

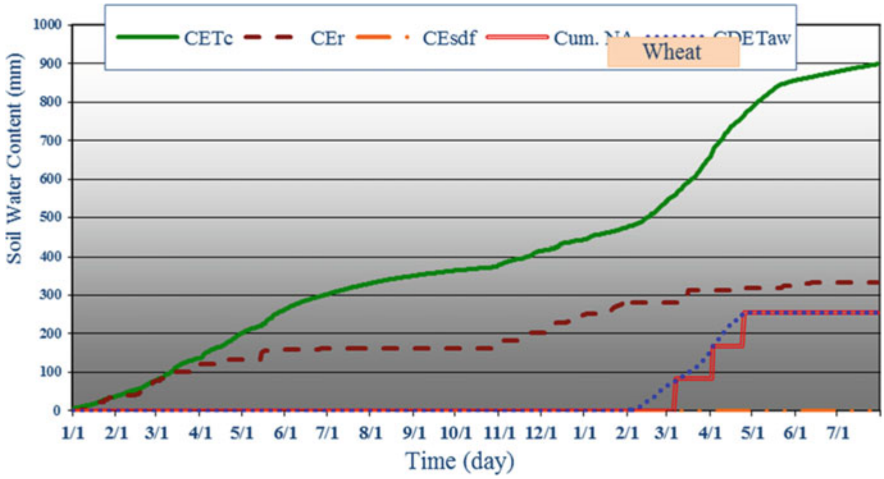


Fig. 6 A plot of CETc, CEsdf, CEr, CDsw, Cum. NA, and CETaw Vs time

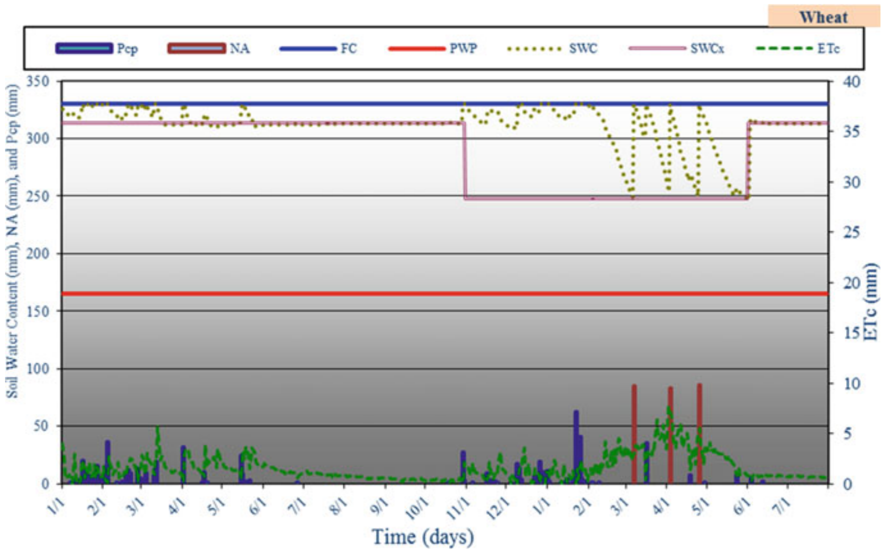


Fig. 7 Fluctuations in soil water content (SWC) between field capacity (FC) and maximum soil water content (SWCx) over the period

soil water content during the growing season. The plot also shows the daily values for crop evapotranspiration (ETc) and rainfall.

Irrigation events are given when the maximum soil water depletion exceeds the maximum soil water content as shown.

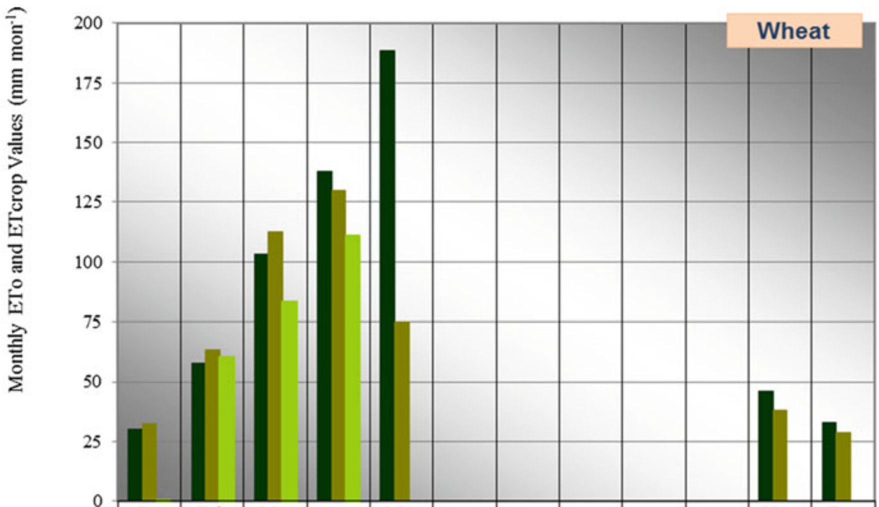
3.6 Total Monthly Values of Reference Evapotranspiration (ETo), Crop Evapotranspiration (ETc), and Evapotranspiration of Applied Water (ETaw)

CUP plus provides a bar graph as a summary of reference evapotranspiration (ETo), crop evapotranspiration (ETc), and evapotranspiration of applied water (ETaw) totals by month during the growing season for the current crop and soil information. The following Fig. 8 shows the total monthly values of ETo ETc and ETaw (mm/month), where ETo arrives at the maximum in May by 188.19 mm/month because of increasing the temperature to the maximum at May but ETaw arrive at the maximum in April by 110.71 mm/month because of stopping adding water after April. Moreover the monthly total reference evapotranspiration (ETo) values over the period of 1 year are 596.12 mm, monthly total crop evapotranspiration (ETc) values over the period of 1 year are 479.85 mm, and monthly total evapotranspiration values of applied water (ETaw) over the period of 1 year are 254.56 mm.

The obtained data agree with Bandyopadhyay and Mallick [6] and French et al. [7].

3.7 Integrity of Weather Data and Quality

The accuracy of determining ETo from weather data is based on the integrity and the quality of the original weather data sets. Therefore, assessments of weather data



	Jan	Feb	Mar	Apr	May						Nov	Dec
ETo (mm)	30.21	57.56	103.21	138.00	188.19	0	0	0	0	0	45.86	33.09
ETc (mm)	32.36	63.13	112.70	130.01	75.23	0.0	0.0	0.0	0.0	0.0	37.89	28.53
ETaw (mm)	0.59	60.08	83.18	110.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Fig. 8 Monthly total values of ETo, ETc, and ETaw (mm/month)

integrity and quality need to be conducted before data are utilized in ET equations. Determining the quality of solar radiation data could be good indicator of the quality of the weather data sets. And that could be evaluated for a particular weather location by plotting hourly or daily average readings of solar radiation (Rs) against computed shortwave radiation that is expected to occur under clear sky conditions (Rso). Under clear sky condition, the value of Rs/Rso returns to one.

Figure 9 shows the values of Rs/Rso of daily measured weather data which represent the general trend of the study location. The values of Rs/Rso ratio are closed. The obtained results shown in Fig. 9 indicated that there is a good agreement between measured and simulated values of solar radiation.

The obtained results shown in Fig. 10 indicated that there is a good agreement between measured and simulated values of maximum air temperature (Tmax) (°C).

The obtained results shown in Fig. 11 indicated that there is a good agreement between measured and simulated values of minimum air temperature (Tmin) (°C).

The obtained results shown in Fig. 12 indicated that there is a good agreement between measured and simulated values of wind speed (u^2) (ms^{-1}).

The obtained results shown in Fig. 13 indicated that there is a good agreement between measured and simulated values of precipitation (Pcp) (mm).

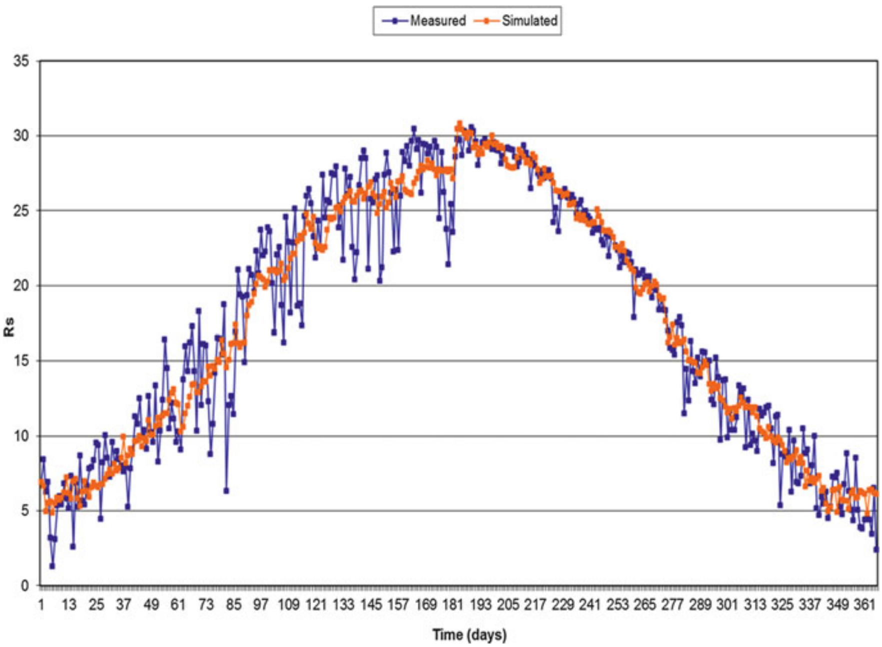


Fig. 9 Comparison of measured and simulated daily solar radiation (Rs)

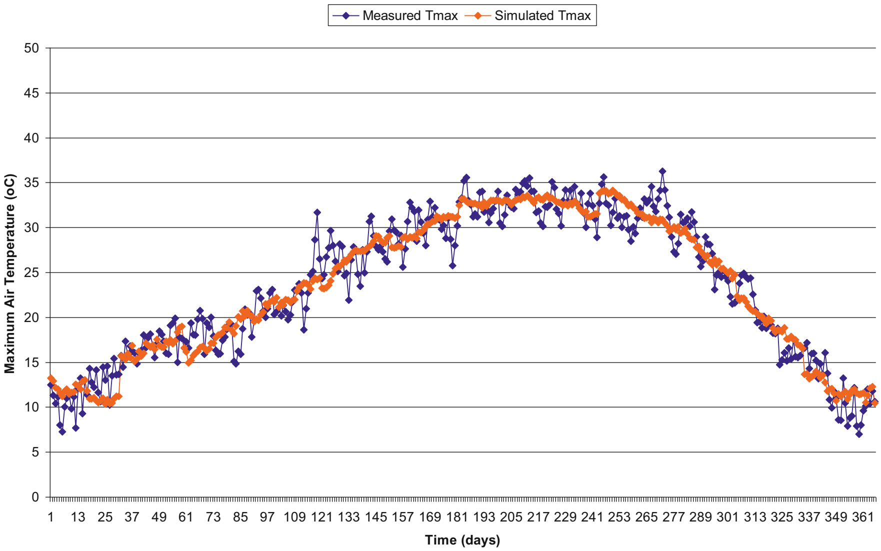


Fig. 10 Comparison of measured and simulated daily maximum air temperature (Tmax) (°C)

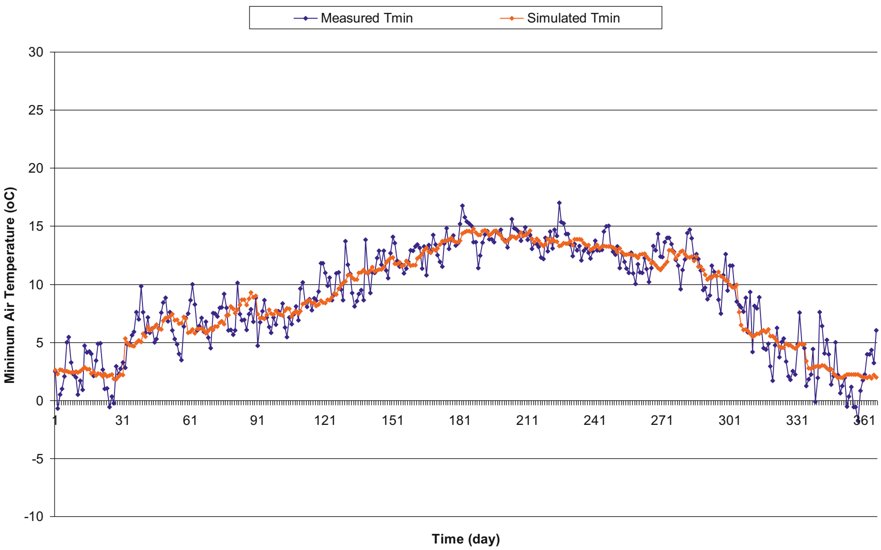


Fig. 11 Comparison of measured and simulated daily minimum air temperature (Tmin) (°C)

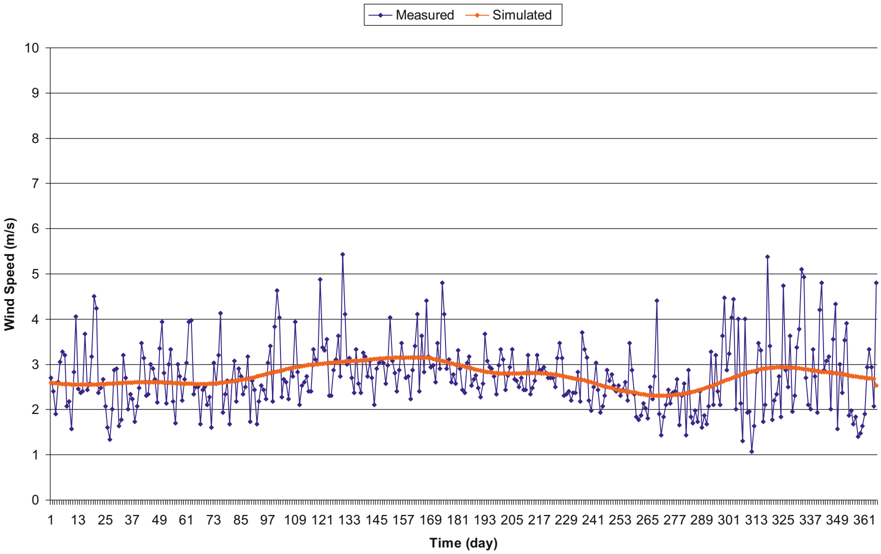


Fig. 12 Comparison of measured and simulated wind speed (u^2) (ms^{-1})

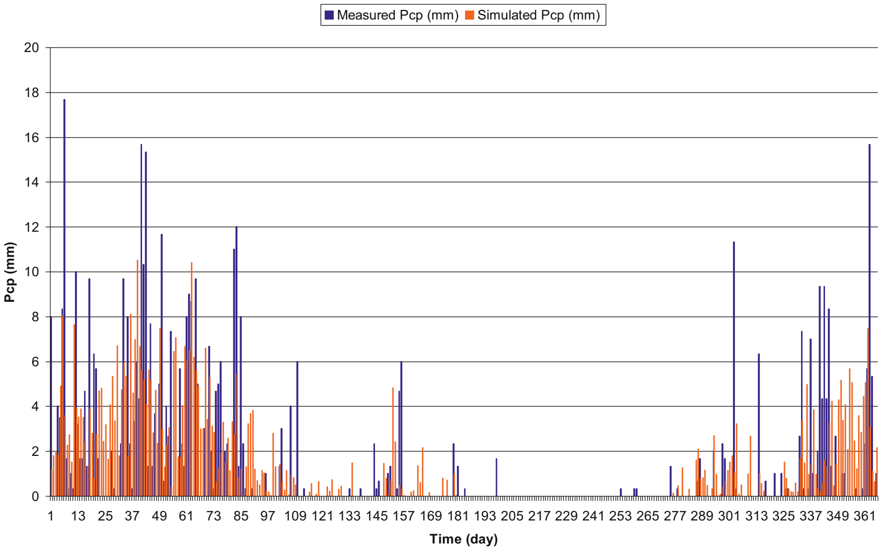


Fig. 13 Comparison of measured and simulated precipitation (Pcp) (mm)

3.8 Simulated and Estimated Daily Evapotranspiration (ETo mm) in Egypt

The obtained results shown in Fig. 14 indicated that there is a good agreement between observed and simulated values of simulated and estimated daily ETo mm/day in Egypt Delta.

4 Conclusion and Recommendations

The Kc values for the wheat have been adjusted for wetting frequency from irrigation and rainfall during the search period. Total monthly values of ETo, ETc, and ETaw (mm/month) can be calculated. ETo arrives to the maximum in May by 188.19 mm/month because of the increase of temperature to the maximum at May, but ETaw arrives at the maximum in April by 110.71. ETo monthly total reference evapotranspiration values over the period of 1 year are 596.12 mm. ETc monthly total crop evapotranspiration values over the period of 1 year is 479.85 mm. ETaw monthly total evapotranspiration values of applied water over the period of 1 year are 254.56 mm. The research examined CUP plus as an efficient tool to evaluate the actual crop coefficient of major field crop (wheat). CUP plus shows high accuracy of

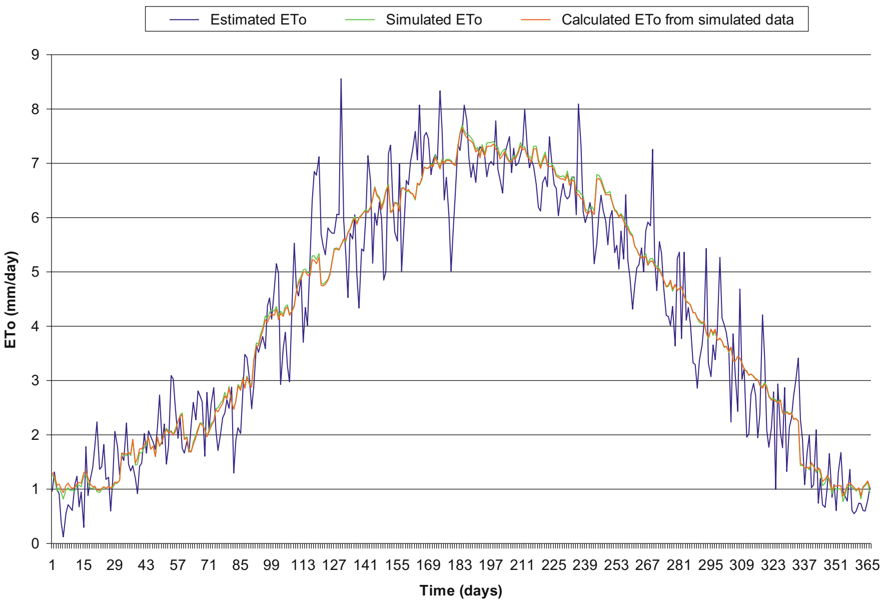


Fig. 14 Comparison of simulated and estimated daily ETo mm/day in Egypt

initial weather parameters needed for calculating ETo, ETc, and ETaw for a longtime series.

CUP plus could be used efficiently to evaluate different irrigation strategies, which support irrigation planning and improvement under Egyptian conditions.

- The SIMETAW model determines effective rainfall and evapotranspiration of applied water (ETaw) for crop and land-use categories, which include similar agricultural crops and other surfaces, by different regions having similar ETo rates within California and Egypt Delta. The model uses daily observed or simulated climate data to account for ET losses and water contributions from seepage of groundwater, rainfall, and irrigation on a daily basis over the period of record to simulate a daily water balance. The model can use daily climate data or daily climate data simulated from monthly data to estimate daily ETo.

  Then, using the surface areas, volumes of water corresponding to crop evapotranspiration and evapotranspiration of applied water are computed for each crop category in each county to provide water demand information that helps on water supply and distribution needs and solutions. This information is extremely important to develop plans for water supply and distribution across the Nile Delta.
- SIMETAW shows high accuracy in simulating the initial weather parameters needed for calculating ETo and simulating ETo and ETc for a longtime series.
- The SIMETAW model simulations provide a method for determining ETo and ETc using minimum weather data set under Nile Delta conditions. The model estimates ETo from generated daily weather data using the standardized reference evapotranspiration (modified) Penman-Monteith equation for ETo, or the Hargreaves-Samani equation, which uses only temperature.
- Based on inputs, the SIMETAW model determines an efficient irrigation schedule for a particular crop and soil.
- SIMETAW model could tremendously help Egyptian irrigation engineers with limited research funding to improve their knowledge of crop water requirements and to address limited water supplies.
- More calibration is required to assess the effect of the interannual climate variability (especially precipitation and wind speed) on the model simulation accuracy.
- More calibration is needed to address the effect of the water stress conditions, and local management procedures in the accuracy of the SIMETAW simulations.
- Since the SIMETAW was calibrated only in the Nile Delta, calibration for the other regions is recommended.

Acknowledgments This research was made possible through grants from the STDF, Ministry of Scientific Research (Project No. 3864), New Approach for Measuring Crop Evapotranspiration and Updating Crop Coefficients in Egypt, and also the help and advice received from R. L. Snyder LAWR, UC Davis, CA, USA, and Morteza N. Orang, DWR, Sacramento, CA.

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Reclamation of Saline-Sodic Soils for Sustainable Agriculture in Egypt

Mohamed K. Abdel-Fattah

Abstract Soil salinity has emerged as the most significant problem of present agriculture of Egypt. Scanty rainfall coupled with high temperature is always conducive to the accumulation of salts. These conditions are predominantly found in Egypt. In Egypt, improving salt-affected soils is essential for ensuring secure agricultural productivity. The study involved leaching experiments on a saline-sodic soil using soil column techniques assessing the efficiency of soil amendments of phosphogypsum (a gypsum-rich material, a by-product of superphosphate manufacture), standard gypsum, sulfuric acid, and rice straw.

The soil amendments used in this experiment were standard gypsum (NG), phosphogypsum (PG), sulfuric acid (SA), and rice straw (RS). Application of the above three amendments was based on the gypsum requirement (GR) equation according to USDA taking in consideration a required final value of exchangeable sodium percent (ESPf) of 12, and an actual exchangeable sodium percent (ESPi) of the initial value of 29.8 was found in the soil.

Air-dried straw was chopped into shredded pieces less than 5 cm long using a suitable hand chopper. The shredded straw pieces at the rate of 130 g/column (60 Mg ha^{-1}) were homogenously incorporated into the soil before the beginning of the leaching process.

The obtained data showed intermittent leaching 0.4 PV (L3) was more effective in decreasing EC, soluble ions, ESP, and exchangeable magnesium and increasing exchangeable calcium as well as improving physical properties (i.e., water-stable aggregates and hydraulic conductivity) than the other ones (i.e., intermittent leaching 0.1 PV or 0.2 PV). On the other hand, the intermittent leaching was more effective in decreasing EC, soluble ions, ESP, and exchangeable magnesium and increasing exchangeable calcium as well as improving physical properties than continuous.

There was a decrease in pH, EC, and ESP values for the degraded soil reclaimed using all amendments. Also, infiltration rate of water increased due to amendments through enhancement of soil aggregation. Also, the thorough mixing application

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showed superiority over the surface application of gypsum, whether standard gypsum "NG" or phosphogypsum "PG" was used.

All amendments proved to have higher efficiency compared to the control treatment. The efficiency of soil amendments will be presented in this chapter.

Keywords Chemical amendments, Normal gypsum, Phosphogypsum, Rice straw, Saline-sodic soils

Contents

1 Introduction

At present 20% of the irrigated worldwide lands are estimated to be salt-affected soils [1]. A vast area (10 million ha) of world irrigated farmland is salt-affected causing significant losses to the annual crop yield [2]. Egypt has about 160,000 ha in Sahl El Tina of salt-affected soil, mostly saline or saline-sodic soil. Reclamation of sodic soils is a vital concern at international level. Saline and/or saline-sodic soils are characterized by high salinity and high exchangeable Na^+ and deficiency of Ca^{2+}. Various amendments have been used for reclamation of such soils. Hydrochloric acid and H_2SO_4 were tested for amelioration and improvement of such soils. These amendments lower the soil pH, react with soil carbonates, and replace the exchangeable sodium with calcium [3, 4]. Gypsum has been successively used in different ways to reclaim salt-affected soils [5, 6]. Sodic soils when clayey, in nature, have very compact mass. Addition of organic manure improves soil porosity and hydraulic conductivity, which may result in improving the rate of percolation of water and penetration of roots of the plants. There are different approaches for reclamation of salt-affected soils. “The prominent ones are chemical, biological, and agronomic. The combination of these approaches not only increases the efficiency but also reduces the time of reclamation” [7]. *Atriplex halimus* is a perennial native shrub of the Mediterranean Basin with an excellent tolerance to drought and salinity [8]. This plant is valued as livestock forage when herbage availability is low [9]. Endowed with an important aerial biomass and complex root system, it represents an efficient and relatively nonexpensive tool in the rehabilitation of degraded lands and in fighting against desertification [10, 11]. The description and conservation of *Atriplex halimus* genetic resources are particularly important for the rehabilitation of disturbed areas by salt and low rainfall. There are four aspects involved in reclamation of salt-affected soils, physical, biological, hydraulic, and chemical.

2 State-of-the-Art Review

Soil salinity in agriculture soils refers to the presence of high concentration of soluble salts in the soil moisture of the root zone. These concentrations of soluble salts through their high osmotic pressures affect plant growth by restricting the uptake of water by the roots. Salinity can also affect plant growth because the high concentration of salts in the soil solution interferes with balanced absorption of essential nutritional ions by plants [12].

2.1 Remediation of Salt-Affected Soils

2.1.1 Remediation by Hydro-Melioration Processes

The practical method to reduce excessive soluble salts in soils is to leach the salts out by the passage of low-salinity water through the active root zone depth of the soil. Several theories have been developed to predict needed leaching, but various required parameters limit their usefulness without on-site calibration [13–15].

Leaching Methods

Keren and Miyamoto [16] summarize the leaching pattern as follows:

1. Continuous ponding: this method is used extensively in the surface irrigated area and usually accomplishes leaching in a shorter period with less cost in slowly permeable fields. The permeability and initial salinity largely control the rate of leaching.
2. Intermittent leaching: this method is especially suitable in fields with the tile drains, as it allows the water table to draw down, which greatly increases leaching

efficiency. When soils develop a surface seal, intermittent ponding may also help water infiltrate by forming cracks.

3. Sprinkling: this method can be used advantageously when the field is unprepared for ponded leaching. It has high leaching efficiency except under high evaporation conditions, such as windy days, but it is energy- and capital-intensive. It is compatible with unleveled sandy soils, especially when water is scarce and costly.

Emerson [17] found that the downward moving soil water enters and leaches salt from the smaller soil pores to a greater extent at lower soil moisture contents. Furthermore, as anion exclusion (negative adsorption) limits the presence of salt in relatively immobile water adjacent to a clay surface, a preponderance of the soluble salts is found with moving soil water. However, Loveday [18] reported that the time required for leaching a clay loam soil was much longer for intermittent ponding, although 50% more water required for reclamation with continuous ponding. Also, the intermittent application of water was more effective in leaching of surface applied salts than continuous leaching as it provides more time for the soluble to diffuse from less mobile water between water applications. Moreover, the lower rates of irrigation leached salt more efficiently than faster ones. Also, salt movement within the slowly irrigated columns occurred at lower soil moisture content than in those of rapidly irrigated columns [19]. Also, the difference in leaching of chloride was observed when the same amount of water was applied continuously or intermittently during the periods of high (7.74 mm/day) and medium (4.51 mm/day) evaporation rates. They added that the large fraction of chloride leached to shallow depths was transported back toward the soil surface due to the prevailing high evaporation rate compared with continuous leaching [20].

In a field experiment, FAO [21] showed and reported that flood irrigation required three times much water compared with sprinkler irrigation to reduce soil salinity by the same value. Sprinkler irrigation also has the advantage that small local differences in the level of the field lid do not cause nonuniform water application and salt leaching. The use of 250 mm applied depth of sprinkler-applied water reduces the salinity of the upper 60 cm of soil to the same degree as 750 mm of surface applied water. They also detected that a small fraction of salt moved up during evaporation from soil previously irrigated by the sprinkler, http://www.fao.org/docrep/x5871e/x5871e04.htm. Abd El-Fattah [22] found that the intermittent leaching showed more efficiency than continuous leaching.

Leaching Requirement and Water Required for Leaching

Leaching Requirement "LR"

Leaching requirement represents the portion of the amount of water that must flow through soil profile removing salt input, included in irrigation waters, to the total amount of applied irrigation water. It is expressed as a percentage. The same parameter may also be expressed in terms of a fraction and is termed as leaching fraction "LF." For low-salinity waters, LR is lower in high-salinity waters. A standard equation for the leaching requirement is as follows [23]:

$$LR = \frac{EC_{iw}}{EC_{dw}} \times 100$$

where EC_{iw} is the EC of irrigation water and EC_{dw} the EC of drainage water. EC_{dw} is considered as the maximum salinity beyond the root zone of the crop.

Water Required for Leaching Saline Soils

The 900 mm depth of river water having EC 2 dS/m was required to effectively reclaim a depth of 100 cm of the soil [24]. On the other hand, applying 400–500 mm depth of the same water in addition to the crop water consumption during the seedling stage was sufficient to established barley and sugar beet plants in a virgin saline-sodic soil. This method saved 50% of leaching water required for reclaiming the soil as compared to intermittent leaching. In the same manner, Gobran and Miyamoto [25] detected a 70% reduction in soil salinity within 90 cm of the soil depth upon application of 1,060 mm depth of water and also a 76% reduction in soil salinity within 60 cm soil depth by applying 1,090 mm depth of water [26]. The application of a depth of leaching water equals to the depth of the soil reduced initial salinity level by 63–83% with an average reduction of 75% [27].

Moreover, the remaining salt could be removed from soil profiles by passing 30 cm of water per meter depth of soil [28]. In the same manner, FAO [29] reported that for leaching of salts, a 30 cm depth of water leached through a 30 cm depth of soil should remove about 80% of the chloride. Furthermore, the application of the first 60 cm depth of water sharply decreased initial soil salinity and sodicity within 50 cm soil depth [30].

The ideal porous matrix system (without pore bypass, dissolution of precipitated salts and salt diffusion constraints, or hydrodynamic dispersion) reported that salinity of soil water passing a given depth in the soil dropped to an equal level of applied water if the volume of applied water equals pore space of the soil volume (i.e., 1 pore volume "PV") [31].

The amount of water for leaching requirement for reclamation should be computed in the light of the following equation $(C/C0)\,(d1/\mathrm{ds}) = k$, where $C/C0$ is the fraction of the initial salt concentration remaining in the soil profile (C: salt concentration after reclamation; $C0$: salt concentration before reclamation); and $d1/\mathrm{ds}$ is the amount of water per unit depth of soil ($d1$: total amount of applied water in terms of water-depth; ds: the depth of soil to be reclaimed) [32]. The constant k varies with soil type and method of water application. The same researcher assumed k values of 0.45, 0.3, and 0.1 for peat, clay loam, and sandy loam soils, respectively; using intermittent leaching the k value was assumed at 0.1 irrespective of soil type. In the same context [33], in large outdoor lysimeter studies, it has been found that 1.5 PV of applied water or 1 PV of drainage water removed nearly all chlorides from sandy loam and clay loam soils. "However, total salt removal, including dissolving soil gypsum, required considerable amounts by a single curve, as $(C/C0)\,(d1/ds\theta) = 0.8$, for all treatments. Where C is a salt concentration in the effluent, C0 is initial salt in soil water, d1 and ds are the depth of water applied and depth of leached soil, respectively, and θ is soil volumetric water content" [34]. In this case, about 60 and 80% of total salt removal occurred with application 2 and 4 PV equivalents of leaching water, respectively [34].

2.1.2 Remediation by Chemical Amendments

Calcium Salts as Chemical Amendments

The most appropriate reclamation procedure depends on the nature of ionic chemistry that affect soil complex. Salt-affected soils are traditionally divided into three broad categories depending on the extent to which they are saline, saline-sodic, or sodic [23]. Reclaiming sodic and saline-sodic soils requires a different approach than saline soils and can be considerably more costly. This is done by adding an amendment that either directly or indirectly releases exchangeable Ca^{2+} or Mg^{2+}. The most common chemical amendments used to correct sodicity are gypsum ($CaSO_4{\cdot}2H_2O$) and sulfur. Other chemical amendments include lime ($CaCO_3$), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), and sulfuric acid. Exchangeable sodium would be removed by these chemical amendments [35]. The calcium ions required for the exchange reaction could be obtained either from the added calcium amendments or from the native calcium carbonate which could be mobilized through the addition of acids or acid formers [18, 36–38].

The saline-sodic soils could be reclaimed by gypsum or sulfur, to replace sodium from the colloid's cation-exchange sites, a process that requires the flow of water through the soil. If the soil profile has limited permeability or if there is an impermeable layer at shallow depths, little or none of the exchanged sodium will be removed, and reclamation will not be accomplished. Once the permeability limiting soil layer is identified, different soil management schemes, in combination with chemical amendments, can be designed to reclaim a saline-sodic soil [39–41].

Also, the gypsum provided decreased the ratio of sodicity to salinity in percolating solution and relatively uniform hydraulic gradient throughout the soil profile [42].

Laboratory experiment by Khamraev et al. [43] showed that application of phosphogypsum (a gypsum-rich material obtained from phosphate fertilizer manufacturer) to saline soils lowered pH and increased infiltration rate. In a soil column experiment, Mahmoud [44] studied applying phosphogypsum and leaching with different increments of water on a saline-sodic soil and found highest salt concentration along with Na^{+}, SO_4^{2-}, Mg^{2+}, and Ca^{2+} in the leachates by application of water equivalent to 4.5 field capacity. This was accompanied by decreasing soil salinity, pH, soluble sodium, and ESP. The application of 8.21 Mg gypsum/fed or 2.0 Mg sulfur/fed to a greenhouse soil provided an appreciable reduction in EC, pH, and SAR with gypsum being more efficient than sulfur [45]. Similar conclusions were reported by Ramirez et al. [46] and Al-Oudat et al. [47].

Using gypsum and other amendments in the reclamation of a sodic soil using intermittent and continuous leaching, Oster [48], Habib et al. [49], and Costa and Godz [50] found that gypsum has relatively higher effect in reducing exchangeable sodium percentage than other amendments.

The application of gypsum for reclamation of sodic soil enhanced the removal of soluble sodium and decreased ESP and pH value of the reclaimed soil. Additional gypsum in excess of the gypsum requirement helped speedy reclamation when water of rather high SAR was used for leaching [51, 52]. While the surface application of gypsum caused 38% increase in water infiltration rate, it increased soil hydraulic conductivity and decreased soil bulk density [53].

The chemical changes due to the application of inorganic amendments (gypsum, sulfur, and lime) in a saline-sodic using cotton and sorghum as indicator crops. They found that sulfur and gypsum were the most effective treatments, decreasing exchangeable sodium from 10.2 to 1.37 and 1.22 cmolc kg^{-1}, respectively [54].

The soil hydraulic conductivity was much higher in case of mixing gypsum with the soil than when gypsum was applied to the soil surface [40].

Laboratory experiments on sodic soils by El-Saadany [55] showed that gypsum decreased soil salinity and decreased soil pH and EC, with increases in soluble Ca^{2+} and available Mn. Also, the gypsum application led to a sharp decrease in exchangeable Na^+, particularly in the upper soil layers, whereas ESP decreased between 13.3 and 15.6 which represents 67.7–77% of the initial ESP values [56, 57].

A laboratory column experiment conducted by Genaidy and Hegazy [58] showed that addition of gypsum decreased pH, EC, and ESP and increased availability of most nutrients for a rice crop. The application of gypsum to soils of El Fayoum and El Sharkia caused a marked decrease in soil pH, EC, SAR, and ESP and exchangeable Na^+, K^+, and Mg^{2+} [59–61]. While application of gypsum in comparison with gypsum/lime mixture indicated that sodicity decreased to a greater extent using gypsum alone [62]. Gypsum application showed a relatively higher effect on reducing ESP of a saline soil as compared with sulfuric acid, calcium chloride, or sulfur [63–65].

Amelioration of sodic and saline-sodic soils by chemical amendments requires high capital input. Cultivation of salt-tolerant grasses may mobilize the native lime ($CaCO_3$) in these soils through root action. The treatment receiving gypsum at a higher rate (100% GR) removed the greatest amount of Na^+ from the soil columns and caused a substantial decrease in soil salinity and sodicity. Grass treatment enhanced leaching of Na^+. "Kallar grass removed more Na^+ during summer than during winter. Effectiveness of the treatments for soil reclamation was in the order: 100% GR > Kallar grass > 50% GR > control" [66].

A field experiment on saline-sodic soil for its reclamation by combining different approaches indicated that gypsum application proved the most effective treatment is giving highest grain yield of rice and wheat. However, this treatment was similar to gypsum + FYM. Combination of gypsum and chiseling remained inferior to gypsum alone or gypsum + FYM. The combination of all the three was not efficient. The pH was reduced after harvesting of the second wheat crop. Soil EC was reduced after growing first rice crop in all the treatments except control. The combination of gypsum + FYM + chiseling was more effective in improving the soil condition [67] than other tested methods.

Acids or Acid-Forming Substances as Chemical Amendments

According to Petrosian [68], commercial grade sulfuric acid could be used for improving sodic soils which have lime (i.e., calcareous sodic soils) since it is cheaper than gypsum. Reclamation of sodic soils [69] was carried out using sulfuric acid as well as gypsum and iron pyrites and concluded that sulfuric acid was more effective but more expensive. Applying sulfuric acid with subsequent plowing to a rice field resulted in positive response promoting rapid soil improvement and increased rice yields [70].

The advantages of sulfuric acid, gypsum, and $CaCl_2$ singly or in combination for sodic soil reclamation. Their results indicate that a combination of amendments may provide efficient reclamation at the lowest cost [18].

The effectiveness of the surface application of sulfuric acid for reclaiming sodic soils [71]. Application of 5–15 Mg/ha proved superior to surface-applied gypsum for calcareous sodic soils. The sulfuric acid was more effective than gypsum in increasing water penetration of a calcareous soil [72]. Hydrochloric acid (HCl) could also be used for reclamation of sodic soils. While ESP and pH values of saline-sodic soils were lowered and infiltration of water increased considerably by application of HCl [73].

The effectiveness of HCl and H_2SO_4 on removing soluble and exchangeable ions in highly sodic sandy loam soil of Wadi El-Natron. They found that the rate of anion removal by HCl and H_2SO_4 treatments was in the following order: $Cl^- > SO_4^=$ $> HCO_3^-$ for HCl and $SO_4^= > Cl^- > HCO_3^=$ for H_2SO_4. The superiority was to HCl, followed by H_2SO_4 [74].

A pot experiment was carried to determine the role of sulfur-oxidizing microorganisms for the reclamation of saline-sodic soils [75]. Results showed that elemental sulfur coupled with a composite culture of sulfur-oxidizing bacteria decreased soil pH, EC, and ESP within 90 days of application.

Elemental sulfur was applied [76] at 0.5 Mg/fed and 1.0 Mg/fed produced a decrease of the soil pH, EC, SAR, and ESP values within 90 days. A 2-year field experiment [77] compared different amendments (gypsum, H_2SO_4, FYM, and sand) on a saline-sodic soil and obtained a decrease in soil pH due to the application of 0.1% sand. The lowest pH, as well as EC, was recorded with gypsum and FYM; reduction in the SAR was significant with the application of gypsum and H_2SO_4 in the second year. Adding sand + gypsum enhanced grain yield of the cultivated crop (rice and wheat). Follett et al. [78] reported that, because of hazards in handling, applying sulfuric acid is difficult under ordinary field conditions, and it is usually applied in irrigation water.

2.1.3 Bioremediation Methods

Organic Substances as Amendments

In general, organic amendments have very little effect in improving soil salinity and sodicity when they are applied alone [79]. Even small amounts of organic matter added to the soil have a positive effect on the physical and biological soil properties including percolation rate, infiltration rate, hydraulic conductivity, permeability, bulk density, total porosity, water-stable aggregates, water-holding capacity, cation exchange capacity, and plant nutrition [80]. Organic matter effectiveness in improving many soil properties is studied by many researchers [81–90]. The reclamation of sodic soils upon applying farmyard manure to a possible release of organic acids and evolution of CO_2 during its decomposition would solubilize the Ca^{2+} from the native $CaCO_3$ [85]. "Applying organic composts to saline sodic soils would help in chelating calcium and decreasing soil pH leading to an increase in solubility of $CaCO_3$" [91]. Also, Anand [92] stated that organic amendments decreased soil sodicity and increased exchangeable Ca^{2+} and Mg^{2+}, while Anwar et al. [93] pointed out that the organic amendment using rice straw and FYM applied with 25% GR was similar to 100% GR in terms of the crop.

Halophyte Plants as Phytoremediation

To improve crop growth and production in salt-affected soils, excess salts must be removed from the root zone. Methods commonly used in the reclamation of such soils are scraping, flushing, and leaching. These methods are expensive. Attention was given to use new technologies of combating salinity, such as using halophyte plants that can tolerate high salinity and remove salts from soil [94]. Halophyte plants include over 80 families; some have specialized leaf cells called salt glands that excrete salt, while others have hairs on their stems that excrete salt, and some have stomatal guard cells controlled by sodium ions [95]. These plants control their transpiration in accordance with the amount of salt in their environment. The use of such plants to reclaim saline soils could be cheaper and more practical than chemical reclamation [96]. Vegetative bioremediation or restoration of saline soils through revegetation is a new strategy for the management of saline-sodic soils [97, 98]. A number of halophytes could be utilized as crops for food, fiber, pot herb, edible oil, fiber materials, and traditional medicines [99, 100].

Using halophytes in reclaiming saline soils has been studied by several investigators (i.e., grasses [66], agronomic crops [101], forest species [102]). Plants that can grow in salt-affected soils may decrease soil salinity/sodicity and help in the dissolution of soil $CaCO_3$ [66] and improve the physical properties by their root action [103]. The biological reclamation techniques using halophytes removed a high amount of Na^+ from the soil and resulted in a decrease in soil salinity and sodicity [66]. Forest shrub species of *Sophora mollis* was used for reclamation of sodic soils [104], in which Chaudhry et al. [105] found that 6 years of growth of *Eucalyptus* plants lowered water table. Acacia also has a similar potential as *Eucalyptus* for bio-drainage. That different annual and perennial halophytes for saline soil reclamation proved that the perennials were more effective [106].

Halophytes can help in the extraction of salts form the soil. These processes include biodegradation of contaminants in the root zone, plant uptake followed by transformation or volatilization, and contaminant stabilization/immobilization. However, "some organic contaminants may be taken up by the plants by a passive process related to the ability of the chemical to move through cell membranes" [107]. Once taken up, certain organic compounds can be metabolized by plant enzymes into less toxic forms [108, 109]. When volatile organic compounds are translocated to plant leaves, they may volatilize through the stomata, where gas exchange occurs [110].

There are growing indications that cultivation of halophytes can be economically feasible for utilizing saline soils [111–113]. Moreover David [114] reported that the cost of phytoremediation is around one-tenth that of conventional soil methods.

Using halophytes was practiced in the Mediterranean region (one example in Spain is given by Moreno et al. [115] and in Egypt by Ghaffer et al. [116] and Kotb et al. [117]). In Australia, the problems originated by forest clearing. In the Mediterranean, there is a limited interest to explore the potential of tree plants such as *Eucalyptus* or *Casuarina* in soil reclamation since there is no need of applying such "biopumps," which are useful in lowering the water table.

The results from 14 experiments with gypsum application (chemical amendments) versus vegetative reclamation (bioremediation or phytoremediation) in sodic soils were estimated [98]. Results were slightly in favor of chemical remediation (62% sodicity decrease versus 52%). However, in bioremediation sodicity was reduced throughout the whole root zone, whereas in chemical remediation it was reduced only in the layer where gypsum was applied. Furthermore, bioremediation improved soil structure and formed macropores enhancing air and water infiltration. The advantages and disadvantages of bioremediation [118] are as follows:

1. Advantages: low initial capital input; promotion of soil aggregate stability and creation of macropores, higher plant nutrient availability; more uniform and greater zone of reclamation; financial or other benefits from crops grown during reclamation
2. Disadvantages: slower action than chemical methods; limited tolerance of plants to highly saline-sodic and sodic soils; the essential presence of adequate $CaCO_3$ in the soil

Bioremediation was compared with chemical remediation and it was reported that lower costs are associated with bioremediation [119]. Considerable research has been done on phytoremediation in saline soils of China (see, e.g., [120–124]). There are studies identifying major environmental factors associated with vegetation patterns in coastal salt marshes of China (see, e.g., [125–130]).

Multivariate analyses including principal component analysis, canonical correlation analysis, and cluster analysis have been used for analyzing soil vegetation relationship [131, 132]. Planting halophytes in saline soils would help in accumulating sodium in leaves and reclamation of saline soils [133]. Recently, Arshadullah et al. [134] used *Atriplex amnicola* for reclamation of saline-sodic soils and obtained positive results in decreasing salinity and sodicity of soils.

3 Experiment Setup and Design

3.1 Aim of Study and Design of Experiment

The study involved leaching experiments on a saline-sodic soil using soil column techniques assessing the efficiency of soil amendments of phosphogypsum (a gypsum-rich material, by-product of superphosphate manufacture), standard (normal) gypsum, sulfuric acid, and rice straw.

3.2 Preparation of Soil Columns and Experimental Setup

Soil material used for the experiment was collected from the top 30 cm, air-dried, crushed, mixed, and passed through a 2 mm sieve. Samples are collected from El-Tina plain, North Sinai Government. Physical and chemical properties of studied soil are shown in Table 1.

For the preparation of soil columns, 64 polyvinyl chloride (PVC) tubes (cylindroid tubes) of 75 cm height and 16 cm inside diameter were used. The bottom of each tube was sealed with perforated mesh nylon screen and glass wool. Acid-washed inert sand (prewashed with HCl and then water) was placed on the tube bottom to make a 5 cm layer of the column to regulate the flow of water and to prevent plugging the lower part of columns with the immigrating fine materials. The soil was packed in tubes so as to a soil column 50 cm high and a bulk density of 1.25 g cm^{-3}. This required a quantity of soil of 12.5 kg of crushed air-dried soil per column. Such arrangement allowed for 20 cm on top of soil column to give sufficient space for the addition of water used for leaching process.

3.3 Amendments

The soil amendments used in this experiment were normal gypsum (NG), phosphogypsum (PG), sulfuric acid (SA), and rice straw (RS). Application of the former three amendments was based on the gypsum requirement (GR) equation [23] taking in consideration a required final value of exchangeable sodium percent (ESPf) of 12 and an actual exchangeable sodium percent (ESPi) initial value of 29.8 found in the soil.

Table 1 Physical and chemical properties of studied soil

Property	Soil
Texture class	Clay
Saturation percent (SP %)	58.30
Bulk density	1.25
$CaSO_4$ (g kg^{-1})	2.9
$CaCO_3$ (g kg^{-1})	10.8
Organic matter (g kg^{-1})	5.5
EC (dSm^{-1})	57.58
pH	8.99
Soluble ions (mmolc L^{-1})	
Na^+	287.20
K^+	16.10
Ca^{++}	63.80
Mg^{++}	208.80
Cl^-	502.20
HCO_3^-	4.80
$CO_3^=$	0.00
$SO_4^=$	68.9
SAR	24.60
Exchangeable cations (cmolc kg^{-1} soil)	
Na^+	9.60
K^+	2.18
Ca^{++}	13.28
Mg^{++}	7.12
Cation exchange capacity (CEC) (cmolc kg^{-1} soil)	32.18
Exchangeable sodium percentage (ESP)	29.80

The NG was of 59.5% purity and its addition rate was 136 g/column. The PG was of 73.9% purity and added at a rate of 110 g/column. The SA was of 98% purity which was added at a rate of 42.5 ml/column. The RS was added at a rate of 125 g/column form of sheared chopped material.

Normal gypsum and phosphogypsum were applied to soil columns in two ways: (a) mixed homogeneously within top 10 cm or (b) within the whole soil column before starting leaching. Sulfuric acid was applied either (a) as one single dose or (b) divided into four equal doses, one at the start and the others during leaching.

Air-dried rice straw was chopped into shredded pieces less than 5 cm long using a suitable hand chopper. The shredded straw pieces at the rate of 125 g/column were homogenously incorporated into the soil before the beginning of the leaching process.

Water collected from El-Salam canal (which irrigates El-Tina plain) was used for the leaching process. The leaching water increments were applied in terms of pore volume (PV) basis. The PV is to the volume of pore space of the soil at the column. The volume of water is used to saturate one soil column (i.e., 1 PV).

Three different PV levels of water were used in the leaching processes, 0.1, 0.2, and 0.4 PV, which are equal to 725, 1,450, and 2,900 cm^3 of water, respectively. The leaching water was applied using intermittent leaching. The amount of water was added in cycling increments. The leachate which mostly equals the added amount of water was collected after the addition of each water increment. Continuous leaching was also done keeping a constant water depth of 36 mm above the column surface, collecting leachates of 0.1 PV (20 leachates).

3.4 Methods Used for Analysis

Each leachate was analyzed for the total soluble salts and soluble ions, followed by termination of leaching soil columns that were separated into three segments as follows: 0–15, 15–30, and 30–50 cm. The soil of each segment was air arid, crushed, mixed, and passed through a 2 mm sieve and analyzed for salinity and soluble ions (in the saturation extract) and pH (in the soil paste) according to the methods described by USDA [23]. “Data were analyzed using the statistical package program MSTAT-C version 2.1 developed by Russel” [135].

4 Results and Discussion

4.1 Salt and Ion Removal as Affected by Leaching Type and Amendment Treatments

The main effect shows the intermittent leaching 0.1 PV “L1” gave the highest salt removal, whereas intermittent leaching 0.4 PV “L3” gave the lowest with 0.2 PV “L2” giving an intermediate removal. The difference between L1 and L2 was not significant. On the other hand, intermittent leaching surpassed continuous leaching. The main effect of amendment treatment shows that all treatments receiving amendments gave greater salt removal. Salt removal by treatments receiving amendments was in the following order: PG+ > NG+ > SA+ > NG++ > SA++ > PG++ > RS.

The main effect of the leaching type shows that L2 gave the highest sodium removal (4,493.4 mmolc/column), whereas L1 gave the lowest (4,376.84 mmolc/column), with L3 giving an intermediate removal (4,381.64 mmolc/column). The main effect of amendment treatments shows that all treatments receiving amendments gave greater sodium removal. Sodium removal by treatments receiving amendments was in the following order: SA+ > NG+ > PG+ > NG++ > SA++ > PG++ > RS.

The main effect shows that L3 gave the highest calcium removal (396.92 mmolc/column), whereas L2 gave the lowest (275.41 mmolc/column), with L1 giving an intermediate removal (334.37 mmolc/column). The main effect of amendment treatments shows that all treatments receiving amendments gave greater calcium removal. Calcium removal by treatments receiving amendments was in the following order: RS > SA+ > SA++ > PG+ > NG+ > NG++ > PG++.

The main effect shows that L1 gave the highest magnesium removal (2,675.42 mmolc/column), whereas L3 gave the lowest (1,748.42 mmolc/column), with L2 giving an intermediate removal (2,543.69 mmolc/column). The main effect of amendment treatments shows that all treatments receiving amendments gave greater magnesium removal. Magnesium removal by treatments receiving amendments was in the following order: PG+ > NG+ > SA++ > SA+ > NG++ > PG+ + > RS.

The main effect shows that L1 gave the highest potassium removal (76.54 mmolc/ column), whereas L3 gave the lowest (24.04 mmolc/column), with L2 giving an intermediate removal (70.56 mmolc/column). The main effect of amendment treatments shows that all treatments receiving amendments gave lower potassium removal. Potassium removal by treatments receiving amendments was in the following order: NG+ < PG+ < SA+ < SA++ < NG++ = RS < PG++.

Concerning chloride, the main effect shows that L1 and L2 gave very similar removal (4,758 and 4,733 Pmmolc/column), whereas L3 gave the lowest (2,895.15 mmolc/column). The main effect of amendment treatments shows that all treatments receiving amendments gave greater chloride removal. Chloride removal by treatments receiving amendments was in the following order: PG + > NG+ > NG++ > PG++ > SA+ > SA++ > RS.

The main effect shows that L3 gave the highest sulfate removal (3,599.31 mmolc/ column), whereas L2 gave the lowest (2,587.83 mmolc/column), with L1 giving an intermediate removal (2,682.56 mmolc/column). The main effect of amendment treatments shows that all treatments receiving amendments gave greater sulfate removal. Sulfate removal by treatments receiving amendments was in the following order: SA+ > SA++ > RS > NG++ > NG+ > PG+ > PG++.

The main effect shows that L3 gave the highest SAR (134.40 mmolc/column), whereas L1 gave the lowest (112.4 mmolc/column), with L2 giving an intermediate SAR (119.57 mmolc/column). The main effect of amendment treatments shows that all treatments receiving amendments produced greater SAR. Values for amendments were in the following order: SA+ > NG++ > NG+ > PG++ > SA++ > PG+ > RS.

4.2 The Salinity of the Soil After Termination of Leaching as Affected by Leaching Type and Amendments

All treatments of leaching or without amendments decreased the salinity of the soil. The initial EC before leaching was 57.58 dSm^{-1} decreased to 3.18 dSm^{-1}.

The main effect shows that L3 had lowest salinity (average 3.98 dSm^{-1}) and L1 had the highest salinity (average 4.52 dSm^{-1}) and L2 was giving an intermediate salinity (average 4.32 dSm^{-1}). On the other hand, intermittent leaching was more effective than continuous leaching. The main effect shows that all treatments decreased soil salinity. The efficiency rating of amendments is PG+ > NG+ = PG++ > NG++ > SA++ > SA+ > RS.

4.3 Soil Reaction (pH) as Affected by Leaching Type and Amendment Treatments

Soil reaction after termination of leaching showed that pH ranges from 7.60 to 8.43. The main effect shows that L3 caused the lowest pH (average 8.18), and L1 caused the highest pH (average 8.25) with L2 giving an intermediate pH (average 8.22). On the other hand, intermittent leaching surpassed continuous leaching. The main effect shows that all amendments showed a range of pH lower than of non-amended soil. The efficiency rating in decreasing soil pH using amendment as compared with the non-amended is SA++ > SA+ > PG+ > NG+ > PG++ > NG++ > RS.

4.4 Soluble Ions and Soil Sodicity (SAR) as Affected by Intermittent Leaching Type and Amendment Treatments

The main effect shows that L3 causes the lowest soluble sodium, average 14.61 mmolc L^{-1}, and L1 causes the highest soluble sodium (average 17.19 mmolc L^{-1}) with L2 giving intermediate soluble sodium (average 16.26 mmolc L^{-1}). The main effect shows that all amendments decreased soluble sodium. The efficiency rating in reclamation of the soil using amendment as compared with the non-amended is PG+ > PG++ > NG+ > NG++ > SA+ = SA++ > RS.

The main effect shows that L3 gave the lowest soluble calcium (average 9.7 mmolc L^{-1}) and L1 causes the highest (average 10.31 mmolc L^{-1}) with L2 giving an intermediate value (average 10.23 mmolc L^{-1}). The main effect shows that all amendments decreased soluble calcium. The efficiency rating in reclaiming the soil using amendments as compared with the non-amended is SA++ > SA+ > NG++ > NG+ > PG++ > RS. PG+ treatment was a different case whereas it increased soluble calcium as compared with the non-amended in all leaching types.

Concerning the amount of soluble magnesium, the main effect was as follows: L1 produced the highest (average 16.38 mmolc L^{-1}) followed by L2 (15.26 mmolc L^{-1}) and then L3 (14.38 mmolc L^{-1}). The main effect shows that all amendments decreased soluble magnesium. The efficiency rating in reclamation of the soil using amendments as compared with the non-amended is PG+ > PG++ = NG+ > NG++ > SA++ > SA+ > RS.

In soluble potassium, the main effect shows L1 > L2 > L3 giving averages of 1.22, 1.18, and 1.08 mmolc L^{-1}. The main effect shows that all amendments decreased soluble potassium. The efficiency rating in reclamation of the soil using amendment as compared with the non-amended is PG+ > PG++ = NG+ > NG++ > SA++ > SA+ > RS.

The concentration of chloride in the soil was arranged as L1 > L2 > L3 in all treatments giving averages of 15.1, 17.48, and 19.1 mmolc L^{-1}, respectively. The main effect shows that all amendments decreased chloride. The efficiency rating in reclamation the soil using amendment as compared with the non-amended is PG+ > PG++ > NG+ > NG++ > SA+ > SA++ > RS.

The main effect shows that the concentration of sulfate in the soil was arranged as L3 < L2 < L1 in all treatments giving averages of 23.30, 24.24, and 24.45 mmolc L^{-1}, respectively. The main effect shows that all amendments increased sulfate. The efficiency rating in reclamation of the soil using amendment as compared with the non-amended is NG+ > PG+ > PG++ > NG++ > SA+ > SA++ > RS.

The data revealed that the initial SAR values were high and dropped sharply after the end of leachate process, where the main effect shows that L1 gave the highest (average 4.67 mmolc L^{-1}) followed by L2 (4.48 mmolc L^{-1}) and then L3 (4.19 mmolc L^{-1}). The main effect shows that all amendments decreased SAR. The efficiency rating in reclamation of the soil using amendment as compared with the non-amended is PG+ > PG++ > NG+ > NG++ > SA+ > SA++ > RS.

4.5 Exchangeable Cations as Affected by Leaching Type and Amendment Treatments

Concerning exchangeable sodium, the main effect shows that L3 caused the lowest contents, and L1 caused the highest with L2 giving intermediate contents. The main effect shows that all amendments decreased exchangeable sodium. The efficiency rating in reclamation of the soil using amendment as compared with the non-amended is PG+ > NG+ > PG++ > NG++ > SA++ > SA+ > RS.

Concerning exchangeable calcium, the pattern took an opposite trend to that of sodium. Differences between the three types are small. The main effect shows that L1 caused the lowest contents, and L3 caused the highest with L2 giving intermediate contents. Concerning exchangeable calcium, the main effect shows that all amendments increased it. The efficiency rating was PG+ > NG+ > PG++ > NG++ > SA++ > SA+ > RS.

Concerning exchangeable magnesium, the main effect shows that L3 caused the lowest contents and L1 caused the highest with L2 giving intermediate contents. The efficiency rating in decreasing exchangeable magnesium due to using amendments as compared with the non-amended is PG+ > NG+ > PG++ > NG++ > SA++ > SA+ > RS.

Concerning exchangeable potassium, the main effect shows that L1 caused the lowest contents, and L3 caused the highest with L2 giving intermediate contents.

Arranging amendments regarding contents of exchangeable potassium shows that RS caused the highest content and NG++ showed the lowest. The order was RS > SA++ > PG+ > SA+ > NG+ > PG++ > NG++.

The main effect shows that L3 causes the lowest ESP, average 11.81%, and L1 causes the highest ESP (average 14.28%) with L2 giving an intermediate ESP (average 13.71%). On the other hand, intermittent leaching surpassed continuous leaching.

The main effect shows that all amendments decreased exchangeable sodium. The efficiency rating in reclamation of the soil using amendment as compared with the non-amended is PG+ > NG+ > PG++ > NG++ > SA++ > SA+ > RS.

4.6 Soil Aggregates (WSA%) as Affected by Leaching Type and Amendment Treatments

The main effect shows that L1 causes the lowest WSA%, average 32.56%, and L3 causes the highest WSA% (average 38.13%) with L2 giving an intermediate WSA% (average 34.81%). The superiority of L3 in increasing WSA% in comparison with L1 and L2 was 17.1 and 9.5%, respectively.

The main effect shows that all amendments increased WSA. The efficiency rating in reclamation of the soil using amendment as compared with the non-amended is NG+ > PG+ > NG++ > PG++ > SA+ > SA++ > RS.

5 Conclusion and Recommendation

Application of chemical amendments enhanced reclamation and caused more decreases in salinity as well as sodicity, and generally, intermittent leaching was more efficient in decreasing EC, soluble ions, ESP, and exchangeable magnesium and increasing exchangeable calcium as well as improving physical properties (i.e., water-stable aggregates and hydraulic conductivity) than continuous. Also, the thorough mixing application showed "on average" superiority over the surface application of gypsum, whether normal gypsum "NG" or phosphogypsum "PG" was used. The studied treatments could be arranged in the following order: PG + > NG+ > PG++ > NG++ > SA++ > SA+ > RS. Concerning PG and NG, results showed that PG showed a relatively greater effect on reducing EC, pH, SAR, ESP, and bulk density compared with NG. This may be explained by Ca^{2+} released from PG which was higher than NG, and this may be attributed to acidity in PG which caused increasing solubility. This study suggests that leaching using amendments led to the improvement of the chemical and physical properties of saline-sodic soils especially with PG followed by NG.

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Impact of Plant Tissue Culture on Agricultural Sustainability

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Abstract Plant tissue culture is an important agricultural biotechnological tool that contributes in the production of crops with improved food, fiber, fuel, and feed. It is one way toward commercialization to face the food availability challenge in developing countries and allow them to cope with their fast-growing population in a restricted area of land. In addition, plant tissue culture enables some rare and nearly extinct plant species to be rescued and propagated. Conventional methods of propagation thus need to be supplemented with modern breeding techniques. In this way, higher levels of agriculture, afforestation, plant improvement as well as in vitro production of metabolites and plant secondary products can be reached and fulfilled on a year-round basis and under disease-free conditions. The main applications of plant tissue culture in the agricultural field, plant micropropagation, inducing new varieties and constrains of plant tissue culture and challenges this technique is facing as an industry helping the agricultural field, are discussed in this chapter.

Keywords Agriculture, Biotechnology, In vitro propagation, Industry, New varieties, Plant tissue culture

Contents

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1 Introduction

Plant tissue culture, as a modern biotechnology technique, is becoming nowadays very important for the development of mankind. It is considered one of the important breeding methodologies for many crops, vegetables and fruits, and it offers a substitute method for conventional vegetative propagation. It can also be considered as an efficient way of clonal propagation (also known as micropropagation); the prefix "micro" is used because this type of propagation is carried in a relatively small space in the lab. This technique produces an offspring totally like the mother plant.

Crops obtained through tissue culture are developed through time-saving and precise approaches compared to conventional plant breeding ones that take much longer. Plant tissue culture allows the rescue of embryos produced by incompatible crosses, prevents the phenomenon of "seed dormancy" observed in some plant species, and shortens the life cycle of some species known to have a relatively long life cycle.

Plant tissue culture is one way to face the food availability challenge in developing countries to cope with its fast-growing population in a restricted area of land. In addition, plant tissue culture enables some rare and nearly extinct plant species to be rescued and propagated. Conventional methods of propagation thus need to be supplemented with modern breeding techniques. In this way, higher levels of agriculture, afforestation, plant improvement, as well as in vitro production of metabolites and plant secondary products can be reached and fulfilled. Developing crops using the conventional ways face several problems such as low quality of the crop output and productivity fluctuations from year to year, which results in a deficit in the supply of the crop as well as its high price. The use of both tissue culture and genetic engineering techniques, combined, made possible the regeneration of plants with a novel character or two or more characters combined in a single plant species, thus saving time and effort of conventional plant breeding programs.

2 Definition and Intended Objectives of Plant Tissue Culture

Tissue culture means the cultivation or culture of specific plant tissues under aseptic conditions. Plants are grown in specific glassware or plastic containers with the addition of nutrients that suit each plant species. Plant tissue culture is based on a specific ability in plant cells, termed "totipotency" [1]. The concept of totipotency is based on the fact that all plant cells (except sperm and egg cells) contain the full complement of genes, which makes it possible to grow individual plant cells into full healthy plants that can be propagated inside the lab (in vitro). This process is also called "micropropagation."

Plant tissue culture is carried under specific conditions of complete sterilization of both the plant tissues as well as all the glassware and utensils used in the process. Plants are naturally contaminated mostly on their surfaces with microorganisms, so their surfaces are sterilized in chemical solutions (usually alcohol and sodium or calcium hypochlorite). This complete sterile medium helps to produce pest- and disease-free plant material [2]. During this process, plant hormones are added to the medium with specific ratios to each species and to each purpose, to control the plant tissue growth and proliferation. The medium can either be liquid, semisolid, or solid (by the addition of a gelling agent: agar).

3 Advantages of Plant Tissue Culture Technique

The following are the main advantages of the tissue culture technique:

- Small size of explant (the portion used in reproduction), used as starting material.
- Production of multiples of plants without the need for seeds or any pollinators.
- Production of mature plants with little space and time.
- Cultivation takes place under sterile conditions, under controlled environmental conditions (adequate temperature and light) which minimize the chance to transmit diseases, pests or pathogens.
- Production of plants from seeds that have a low germination rate.
- Regeneration of whole plants from genetically modified cells.
- Easy to maintain, move these plants and store them until needed, irrespective of the season and weather.
- This technique in plant breeding is characterized by increasing the plant yield and quality with lower production costs compared to traditional breeding methods.

In this chapter, we will discuss four applications of plant tissue culture technique that are being used in the agricultural field; these are (1) micropropagation, (2) organogenesis, (3) somatic embryogenesis, and (4) protoplast culture.

4 Micropropagation

Basically, micropropagation is like rooting of plant cuttings and might also be considered as another method of vegetative propagation of plants. However, it differs from the conventional method in that it is carried out in complete aseptic conditions and requires unique conditions, i.e., an artificial nutrient medium supplemented with specific growth factors.

It is used to sustain agriculture and is an example of direct laboratory to soil transfer of biotechnological benefits. A small plant cutting or explant (usually an axillary bud) is surface sterilized and inoculated into a culture vessel containing a solid or semisolid nutrient medium and supplemented with the proper ratio of auxin/cytokinin. The inoculated culture vessel is incubated at room temperature, (Fig. 1) [3].

In a day or 2, many shoots develop from the axillary bud in a process known as axillary bud proliferation. After that, each growing point is subcultured (i.e., cultured in a new fresh medium) to give rise to a new shoot. This phenomenon is known as adventitious shoot formation (adventitious refers to an organ grown in a place different from its normal position). Auxin stimulates each shoot to develop roots. After the root emerges, the new plantlet is transferred to the field.

5 Organogenesis

Organogenesis refers to the differentiation of organs, such as shoot and root, from an undifferentiated mass of cells. The process depends on the fact that the cells of an explant (the part of the plant to be used in culture) are highly differentiated because

Fig. 1 Plant tissue cultures being grown at a USDA seed bank, the National Center for Genetic Resources Preservation. By USDA, Lance Cheung – Flickr, Public Domain, (https://commons.wikimedia.org/w/index.php?curid=44757726)

they are taken from a differentiated plant part such as a root, a stem, or a leaf. When an explant is placed in an artificially enriched nutrient medium, its differentiated cells start to dedifferentiate (which means to return to an undifferentiated state) to form a mass of unorganized cells known as "callus."

The cells of the callus then redifferentiate and produce the desired tissue in response to specific growth regulators added into the medium (plant hormones). This tissue develops then into an organ.

Single cells can also be cultured and induced to develop shoot and root one followed by the other by the addition of proper plant hormones combinations. Plant growth regulators (hormones) relative amounts to each other play an important role in the differentiation process.

There are two important groups of plant hormones that play the most important roles in plant tissue culture: auxins and cytokinins. Auxins, such as indole acetic acid (IAA) and naphthalene acetic acid (NAA), promote root differentiation and cytokinins such as kinetin and adenine promote shoot differentiation. A balance of both auxin and cytokinin usually produces a callus [4].

It has been established that root and shoot differentiation depends on the ratio or quantitative interaction between cytokinins and auxins [5]. This principle is applied to plant cells or tissues cultured in vitro. Kinetin and IA are added to the in vitro culture in required specific amounts and ratios, one following the others to promote shoot and root differentiation.

6 Somatic Embryogenesis

In flowering plants, the fusion of two gametes leads to the production of an embryo. The resulting plant embryo follows a preprogrammed development through a series of differentiation events to develop into a mature embryo that results in the formation of a plantlet [6]. Under normal conditions, embryos result from sexual reproduction through the formation of a zygote and are thus known as "zygotic embryos."

A different type of embryos can be developed by plant tissue culture techniques; the embryo is like a zygotic embryo in shape, but it is formed from a somatic cell, not from reproductive ones thus bypassing sexual reproduction. Such embryos are known as "somatic embryos." They are bipolar [7]. The formation of somatic embryos is known as somatic embryogenesis.

Somatic embryo formation starts with a mass of single cells or a tissue grown on a semisolid nutrient medium. A cell keeps dividing and forms a cell aggregate. The cell aggregate passes through different stages including globular, heart-shaped, and torpedo stages.

The torpedo stage is the mature stage. The culture is initially started on a semisolid medium, and the obtained callus is transferred to a liquid well-agitated and aerated medium. The callus is broken down into cells that will each develop into a somatic embryo. Mature stages of somatic embryos are sorted out, transferred to a semisolid medium, and grown to maturity to obtain a regenerated plant (Fig. 2).

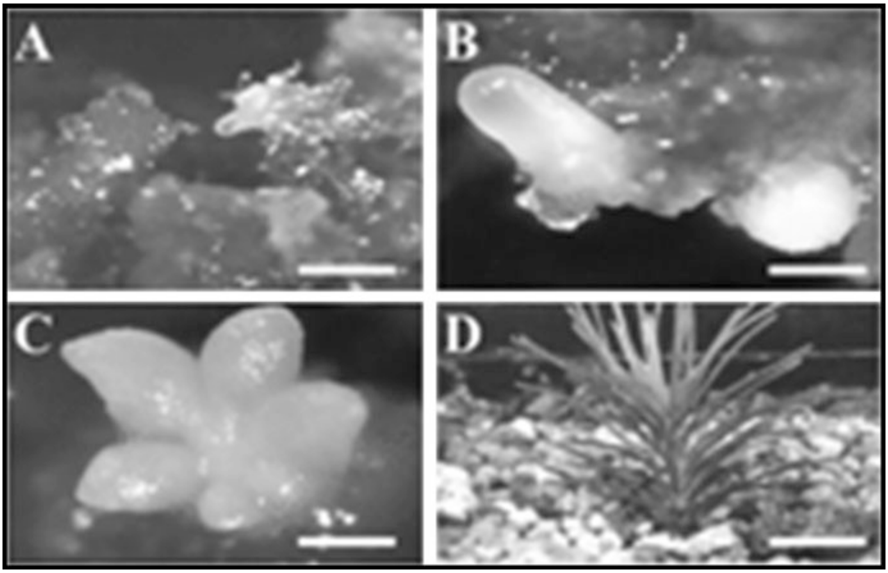

Fig. 2 Regeneration through somatic embryogenesis in slash pine. Different stages of embryo development are noticed, (**a**) embryogenic callus, obtained from zygotic embryo (bar = 0.1 cm), (**b**) globular somatic embryo (bar = 0.5 cm), (**c**) cotyledonary somatic embryo (bar = 0.5 cm), (**d**) regenerated plant, established in soil (bar = 0.8 cm) (adapted from [8])

There are four ways by which somatic embryos could be transferred to the field. These methods are briefly explained below:

1. Germination of somatic embryos takes place in the laboratory; they are then transplanted into pots and then transferred to the field.
2. Encapsulation of dormant embryos takes place in a gel, containing a proper nutrient for the embryo. These encapsulated embryos are known as “artificial/synthetic seeds.” These seeds have the advantage to be easily planted in the field.
3. Germination of embryos under controlled conditions: Emerged seedlings are mixed with a gel like medium. The seedling-gel mix is then sown in the field.
4. The embryos are germinated and then used in a viscous carrier gel, supplemented with growth regulators, sucrose and nutrients, a process known as “fluid drilling.” The major advantages of this process are (1) the rescue of zygotic embryos initiated by distant incompatible crosses and (2) the ability to overcome seed sterility and dormancy.

7 Protoplast Culture and Fusion

Protoplasts can be defined as the spherical plasmolyzed content of plant cells whose cell wall has been removed. The cell remains bound by a plasma membrane [9]. Figure 3 illustrates the culture of protoplast isolated from embryogenic callus of date palm [10]. Protoplast fusion enables combining useful characters from two plant species in one species. The concept is that isolated protoplasts from two different species of plants are induced to fuse to produce a single protoplast containing both the genetic material and the cytoplasm of both fused protoplasts.

Fusing two protoplasts is not direct or straightforward; it should be induced by some agents, called "fusogens." There are two types of fusogens: chemical and electrical. Polyethylene glycol (PEG) is a chemical fusogen. However, it cannot be considered a universal fusogen, since it is toxic to some types of plant protoplasts. Another way is the use of a direct electric current applied to the fusing protoplasts. This method is known as electro-fusion. The product of the fusion of two protoplasts is called "a synkaryon."

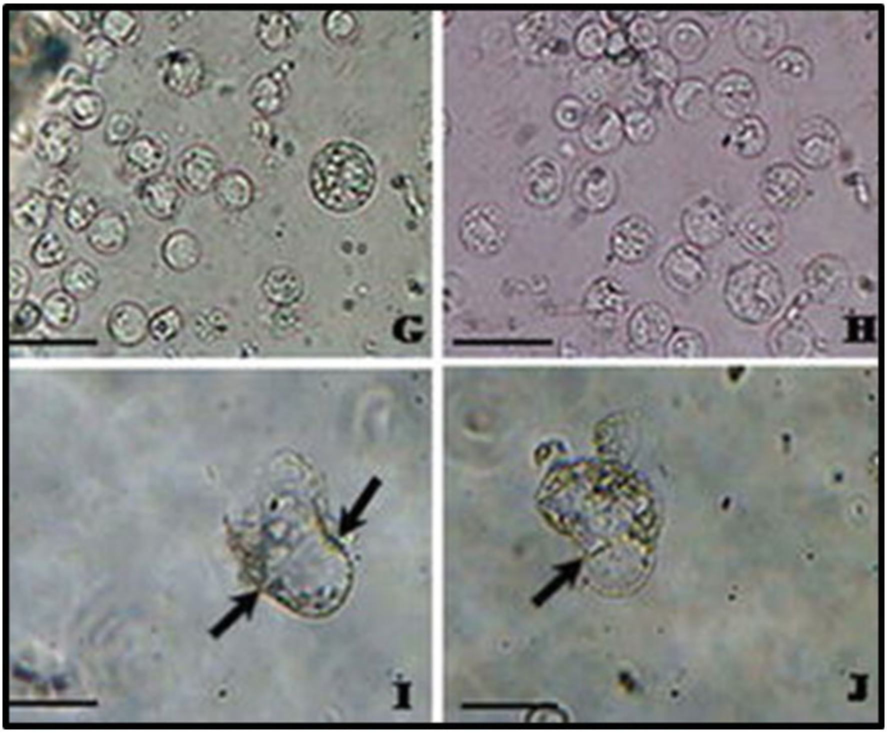

Fig. 3 Date palm protoplast culture as a method of palm micropropagation: (**g**–**h**) isolated protoplasts (bar = 30.5 μm), (**i**–**j**) first cell divisions of protoplasts after 3 days of culture (bar = 9.5 μm; *arrows* indicate separation of the cells after division and thickening of the protoplast periphery due to regeneration of a new cell wall) (adapted from [10])

Protoplast fusion takes place in three steps. First, two protoplasts are laid close to each other. Second, the plasma membranes of both cells fuse, and then the two nuclei lie in the mixed cytoplasm. This stage is known as "a heterokaryon." In the third and last stage, the two nuclei fuse leading to the formation of a synkaryon.

After synkaryon formation, a cell wall is regenerated around the fused protoplasts, and the cell is cultured in a defined artificially enriched nutrient medium. This sequence of events is very like what happens in the case of callus culture. This process is also known as somatic hybridization, and the products are known as "somatic hybrids."

This method overcomes the difficulty of the fusion of gametes of two unrelated plant species. Carlson et al. [12] obtained the first somatic hybrid by fusing the isolated protoplasts of *Nicotiana glauca* with *N. langsdorffii*. However, in some cases, two nuclei cannot coexist due to cellular incompatibility. As a result, one nucleus is eliminated, and the result is a protoplast containing the cytoplasm of both species but the nucleus of only one species. In this case, the resulting hybrid is known as a cytoplasmic hybrid or cybrid.

Somatic hybridization is carried in sexually incompatible plant species. A well-known example of a somatic hybrid is "pomato." Pomato was obtained by fusing the protoplasts of potato and tomato. However, this hybrid is of little commercial value [12].

8 Success in Developing In Vitro Protocols for Crop Plants

Biotechnological application of crop improvement programs requires a reproducible and efficient system for in vitro regeneration. An in vitro plant regeneration technique refers to culturing, cell division, cell multiplication, and dedifferentiation and differentiation of cells, protoplasts, tissues, and organs on specific defined solid or liquid medium under sterile conditions and physically controlled environment [13]. A reliable successful in vitro regeneration technique is of great importance to obtain complete whole plants starting from simple cells either through clonal propagation methods or genetic engineering of plants (Genetic Engineering of Plants: Agricultural Research Opportunities and Policy Concerns (1984).

In its beginning, tissue culture was most commonly used for high-value horticultural crops. However, today, tissue culture propagation has also been very successful in producing improved self-sufficient crops widely used in developing countries [14]. One notable advance and improvement made possible by tissue culture was the development of disease-free bananas in East Africa. Bananas are considered a major source of nutrition and income in many countries of Africa. Rice is another crop whose demand increases rapidly in West Africa and cannot be fulfilled by local production only. The region imports around 6 million tons of rice annually (half of the region's requirements) at a cost of about US$1 billion. To address this decrease in product, Monty Jones, a Sierra Leone scientist working at the Africa Rice Center (previously WARDA), started a breeding program based on tissue culture techniques to develop crosses between an African species of rice (*Oryza glaberrima*) and an Asian species (*Oryza sativa*). The former is better adapted to local environments with a drawback of producing lower yields (around 1 ton per hectare), whereas the latter has the advantage to yield around 5 tons per hectare.

Numerous embryos were obtained by crossing the two species, but these were grown to maturity only with the use of tissue culture. The obtained "new rice for Africa" were called "NERICAs." They have the advantage of being tolerant to many different severe conditions and yield a much higher product [15].

Cassava is a major staple crop for millions of people in tropical countries in East and Central Africa, supplying a great portion of the energy need mostly in the agricultural areas, and it is the second most important staple crop in Africa after maize [16]. Cassava is highly susceptible to many diseases and pests especially African cassava mosaic disease which can result in a huge yield loss reaching 100% [17]. Frog-skin disease, which affects cassava, has been eliminated from five different cassava cultivars using a combination of heat treatment and tissue culture. Tissue culture may enable the development of disease-free cassava varieties in Africa as innovations seek to lower the cost of application of the technology [18].

Date palms, potatoes, citrus, and stone fruits are also grown in many areas of the world including Egypt using tissue culture techniques. A study concluded by Khaled et al. [19] showed that banana grown by tissue culture outperformed banana grown under traditional farming at the level of all the studied economic variables, where average profit from tissue-cultured banana reached around 591% of the profit realized from traditionally produced banana. In addition, it was found that tissue-cultured banana is better in terms of shape, taste, and nutritional value, in addition to obtaining a virus-free crop. Therefore, the study recommended supporting and improving banana production by tissue culture, as a replacement for traditional production to raise the crop productivity and exports of Egyptian banana [19].

Date palm is also a major agricultural crop that has great nutritional value and health benefits. It is propagated either sexually by seeds or vegetatively by off-shoots. Seed propagation has some limitations such as high percentage of male plants and slow growth [20].

The use of tissue culture in case of date palm has proven to be a very convenient method for large-scale multiplication. It enables the production of a high-quality and uniform planting material under sterile disease-free conditions on a year-round basis, irrespective of the weather or season. Two main tissue culture methods are used for date palm micropropagation, somatic embryogenesis, and organogenesis. Inflorescences were also used as good promising explants of elite cultivars of date palm [20].

9 Problems Associated with Plant Micropropagation

Plant tissue culture is known to generate a range of variability between cells of the same tissue. This variability is known as "somaclonal variation." This variation between cells might be due to spontaneous gene mutation or changes in epigenetic marks. This variation might be a disadvantage for in vitro cloning when one's objective is to obtain a true-to-type plant progeny.

On the other hand, somaclonal variation is very beneficial when the breeder's goal is to obtain genetic variation, particularly in the case of plants that are propagated asexually, those that are hard to breed or those with a narrow genetic base, having only few cultivars available [21]. Genetic variations occur in various types of cells such as calli, undifferentiated cells, and isolated protoplasts [22].

10 Production of New Plant Varieties with Tissue Culture

In tissue cultures, variations are detected between cells of the same tissue. These variations are attributed to the phenomenon of somaclonal variation [23]. There are many factors that might cause these variations such as wounding, oxidative stress, imbalance of media components, sterilization processes, and improper physical conditions of the culture such as light and humidity. Plants are exposed to oxidative stress that results in accumulation of reactive oxygen species (ROS), such as hydrogen peroxide, superoxide, peroxyl, hydroxyl, and alkoxyl which may result in genetic mutations such as changes in chromosome number, rearrangements, or epigenetic modifications, not due to any change in DNA sequence. Epigenetic modifications include DNA hyper or hypomethylation. This is the reason explaining why sometimes somatic embryogenesis is a preferred method to obtain uniform plants because DNA in the initial stages of embryogenesis normally contain lower levels of methylation [24]. Also, the number of subcultures and the duration of each one influence the rate of somaclonal variations [25].

Also, in oil palm, in vitro proliferation was found to induce DNA hypermethylation, and changes in DNA methylation may change the expression of embryogenic capacity during tissue culture [26]. Several plant growth regulators (PGRs) used during tissue culture such as 2,4-dichlorophenoxy acetic acid (2,4-D), naphthalene acetic acid (NAA) and BAP (6-benzylaminopurine), and synthetic phenylurea derivatives (4-CPPU, PBU, and 2,3-MDPU) have also been found to be involved in somaclonal variations. Kinetin was found to cause severe hypomethylation of DNA in proliferating cultures of carrot root explants within 2 weeks [27], and auxins, including NAA, on the other hand, were found to cause hypermethylation [28].

Some in vitro multiplication techniques were found to be associated with "somaclonal variation" [29]. Regenerated plants with some aberrations can develop from genetic- and/or epigenetic-mediated gene expression alterations and can sometimes result in significant economic losses. For example, around 5% of commercial oil palm (*Elaeis oleifera*) plants regenerated via somatic embryogenesis bore somaclonal abnormalities that included the mantled inflorescence syndrome [30]. This disease was later found to be associated with changes in DNA methylation status [31] and was also associated with the use of specific plant growth regulators, hormones, and nutrients that were added to the culture media [32, 33].

The nature of the in vitro propagation system used to produce regenerated plants can influence the chance of producing significant quantities of somaclonal variant plants. A higher chance to produce genetic and/or epigenetic changes in regenerated plants is usually linked to in vitro propagation systems that depend on a two-stage process to generate new plants by passing through an intermediate callus stage (such as in somatic embryogenesis) [34].

First, cells from the explant material must dedifferentiate to form unspecialized callus cells. Second, some of these callus cells must redifferentiate to allow for the development of the specialized cells needed to form tissues and organs. Rodríguez López et al. [35] showed that the *C*-methylation profiles of leaves from plants developed by somatic embryogenesis in cocoa (*Theobroma cacao*) had many of the features of the explant tissue as well as some of those in the leaves of the mother plant. This finding suggests that the epigenetic DNA methylation landscape (and therefore the global gene regulation patterns) is not entirely dedifferentiated in the callus cells before new adventitious plant tissues develop.

11 Advantages of Somaclonal Variation in Plants Produced by Tissue Culture

Somaclonal variation is the variation resulting from chromosomal rearrangements in plants grown by tissue culture and specially those regenerated through a callus phase. The resulting variation can be genotypic or phenotypic. Phenotypic variation might be genetic (pre-existing in the somatic cells of the explant) or epigenetic in origin (caused by temporary phenotypic changes and not cause by any change in DNA sequence). Somaclonal variation may have physiological, genetic, or biochemical cause/s. Physiological causes include exposure of the culture to plant growth regulators with different ratios. Genetic causes include changes in chromosome number and/or structure as well as gene mutation and transposable element activation. Biochemical causes include lack of photosynthetic ability due to alteration in carbon metabolism, starch biosynthesis via carotenoid pathway, nitrogen metabolism, and antibiotic resistance [21]. Somaclonal variation in plants may have its advantages in crop improvement, creation of additional beneficial genetic variations, increased and improved production of secondary metabolites, and selection of plants resistant to various toxins, herbicides, high salt concentration, and mineral toxicity.

12 Hardening and Field Establishment of In Vitro Grown Plants

Hardening is the acclimatization of tissue culture grown plants and their gradual exposure to soil which is the ultimate success of in vitro propagation [36]. Hardening or ex vitro acclimatization of plants grown by tissue culture is considered the bottleneck for commercializing these plants. Researchers use different approaches to establish these plants in soil with the maximum possible efficiency. Rooting is very important for hardening. In addition, when in vitro grown plants are transferred to soil and exposed to ex vitro conditions, they suffer from losses due to environmental changes which sometimes might lead to plant mortality. The level of plant acclimatization and photosynthetic apparatus was found to be affected by the type of media, hormone amount and concentration, concentration of sucrose and the gelling agent, temperature, and pH [37, 38]. Different types and combination of substratum have been used as potential possible ways for a better hardening process. For example, a combination of charcoal pieces and mosses was found optimum for epiphytic orchids, and a mixture of moss and decayed food was preferred for terrestrial ones. In addition, manipulation in salt solution added to a matrix or substrate was used for hardening of in vitro raised *Carica papaya* [39], and soaked cotton was used for successful hardening of *Saccharum officinarum* [40]. Bacterial inoculations are sometimes effective in improving the survival rate of tissue culture grown plants. The term “biotization” refers to a technique analogous to vaccination where physiological changes take place in the plants by plant growth-promoting bacteria when they are transferred into soil. This process enhances the tolerance of these plants to both abiotic and biotic stress which helps the plants to better survive during hardening. Cost-effective approaches for hardening of plants constitute a challenge that the scientists need to approach and try continuously to find new alternatives for plants grown in vitro to adjust to the new growth conditions ex vitro [41].

13 Constraints of Plant Tissue Culture

Plant tissue culture in vitro is a powerful technology that has a promising role in sustaining agriculture and a great potential to produce elite plants with superior quality, with the use of little chemicals. However, this industry is technology driven and requires labor, energy, trained personnel, and specific equipment which are not always available. Acclimatization of in vitro grown plants is often an expensive part of the technology and requires greenhouses to obtain suitable end products. In summary, this technique must be handled very carefully. Otherwise, non-desired unproductive products will be obtained.

14 Conclusion

Plant tissue culture has many applications in the field of agriculture and has proven to be a successful industry allowing the increased production of important crop plants and has thus contributed to the Second Green Revolution. Increased rate of crop production as well as improved crop varieties will be facilitated with plant tissue culture techniques, providing all necessary treatments, equipment, and personnel that are available. Improving and investing in plant tissue culture will thus likely have a great effect in agriculture sustainability and in creating several employment opportunities in the field of agriculture industry.

15 Recommendations

Future research in the field of plant tissue culture should focus on the production and propagation of genetically homogenous disease-free plants and specially the important economic crops to meet the continuously increasing world demand. Somaclonal variation is considered an important source of genetic variability that should be exploited to obtain new stable genotypes that can be grown in different types of soil. In vitro culture of zygotic embryos should be used to recover plants obtained from intergeneric crosses that do not yield fertile seeds. Plant tissue culture is an indispensable tool for genetic engineering in plants to grow plants that are tolerant to both biotic and abiotic stress factors. Decision and policy makers are highly encouraged to invest in new plant tissue culture techniques that suit the agriculture of different crop varieties and in different parts of the land.

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Part III
Integrated Biopesticides and Biofertilizers for Sustainable Agriculture

Pesticide Alternatives Use in Egypt: The Concept and Potential

Atef Mohamed Khedr Nassar

Abstract Pest management programs include physical, mechanical, cultural, and legislative strategies, resistant varieties, activation of host plant defense mechanisms, biological control agents, and synthetic pesticides. Yet, the application of synthetic pesticides is the main control method, which heavily contaminates the environment and affects the quality of produced crops and the safety of humans. Therefore, scientists around the world and in Egypt are investigating numerous alternative approaches including plant natural extracts, specific secondary metabolites, intercropping crops (the allelopathic and/or defense inductive effects), and nanoformulations of secondary metabolites and/or pesticides. These alternatives showed promising potential as anti-pathogenic agents. The current chapter will accentuate the contribution of the Egyptian scientists in the area of using natural plant chemicals as pesticide alternatives or additives. Also, presented herein is a summary of the application of nanomaterials, nanoemulsions, nanoencapsulation, and nano-pesticides in the IPM systems. However, there are thousands of research articles and patents that describe the immense potential of nanotechnology and natural materials as alternatives to the synthetic pesticides. There is very limited number of registered commercial products either in Egypt or worldwide.

Keywords IPM, Nano-pesticides, Phytopathogens, Plant secondary metabolites

Contents

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1 Introduction

Various crops are grown in Egypt; cereals (rice, wat, and maize), fiber crops (mainly cotton), sugar crops (sugarcane and sugar beet), food legumes (broad beans and soybeans), forage crops (clover), fruits (citrus, grapes, stone fruits, pome fruits, and tomatoes), vegetables (strawberry, potatoes, peppers, cucumber, cucurbits, and many others), and herbal and spices crops. These crops are attacked by many plant-pathogenic bacteria, fungi, insects, nematodes, weeds, etc. Therefore, millions of tons of pesticides are applied yearly in Egypt to control these pathogens. According to FAO statistics [1], in 2014, Egypt used 2,274, 3,113, and 5,976 tons of herbicides, insecticides, fungicides, and bactericides, respectively, to a total of 11,363 tons (Fig. 1). The application of pesticides would save the plants' yield (quantity and quality) but would put a huge burden on the environment, human health, and wildlife. Therefore, finding alternatives and/or synergistic agents of pesticides has been the major task of thousands of scientists all over the world.

Plants are considered as a never-ending bank of active components (thousands of natural products; secondary metabolites). The practice of using plant derivatives as

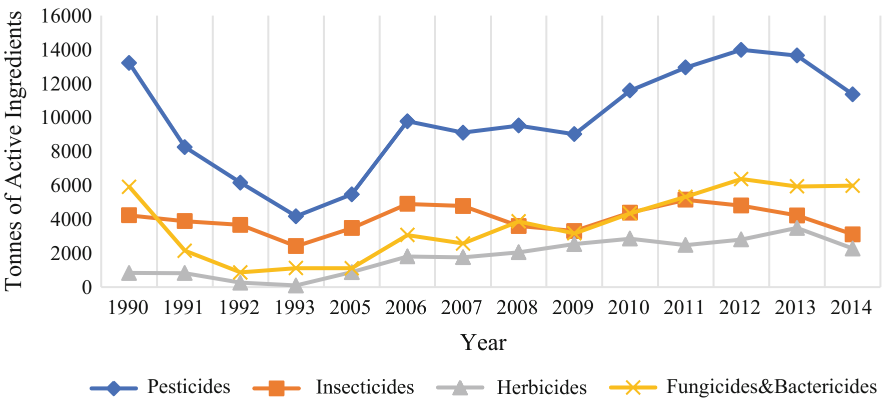

Fig. 1 Pesticides used in Egypt through the period of 1990–2014 [1]

botanical pesticides in agriculture dates back at least two millennia in ancient Egypt, India, China, and Greece. In Europe and North America, the documented use of botanicals pesticides extends back to more than 150 years [2]. Pliny the Elder described mint (pennyroyal) *Mentha pulegium* as insect control material in Europe. Also, the wormwood (*Artemisia absinthium* L. and related species) was reported as repellents of fleas and moths [3]. At the beginning of the eighteenth century, countless active chemicals from various plant species were identified and were used as precursors in the pesticide industry.

For example, the pyrethrins, the extract of *Chrysanthemum cinerariaefolium* plants, are used as safe natural insecticides to mammals, environment, and birds. But its stability encouraged the industrial synthesis of the more stable, pyrethroid insecticides [4]. Rotenone (isoflavone) and related insecticides were extracted from several genera of Leguminosae, the leaves of *Derris* sp. and seeds of *Tephrosia* sp. [5]. Nicotinoids were coined as potent insecticides from tobacco plants (*Nicotiana tabacum*, Solanaceae) [6]. Also, plants of the Solanaceae family synthesize several other alkaloids and glycoalkaloids including chaconine, solanine, tomatine, atropine, and scopolamine, which exert powerful insecticidal effects [7]. The alkaloid, ryania, was first extracted from stems and roots of the South American plant, *Ryania speciosa* (Flacourtiaceae); in addition to ryanodine, 11 other ryanoids from other plant species were identified with different insecticidal activity [3]. Sabadilla, strychnine, and atropine alkaloids have been used to protect the plants against herbivory [2]. The insecticidal activity of caffeine, cocaine, nicotine, morphine, theobromine, and the other cannabinoids was reported as effective insecticides [8]. Precocenes were isolated from the leaves of *Ageratum houstonianum* and used as anti-juvenile hormones of insects [9]. In the early 1990s, scientists at the US Department of Agriculture (USDA) discovered that sugar esters of wild tobacco (*Nicotiana gossei*) had pesticidal bioactivities to certain soft-bodied insects and mites. Moreover, the AVA Chemical Ventures (in the USA) has patented and registered an insecticide/miticide based on C-8 and C-10 fatty acid mono-, di-, and tri-esters of sucrose octanoate and sucrose dioctanoate [10].

The annonaceous botanical pesticides were prepared from the seeds of the *Annona* sp. (Annonaceae) including the sweetsop (*A. squamosa*) and soursop (*A. muricata*). The insecticidal activity was due to the presence of the acetogenins (long-chain fatty acid derivatives): annonin and squamocin [11]. Acetogenins were patented in 1987 as insecticides in Germany by Bayer AG Company [12] and in 1988 in the USA by Mikolajczak and McLaughlin [13]. The extracts of the neem tree (Meliaceae) showed insecticidal and nematicidal effects with high safety index to mammals [7]. New insecticidal chemicals are still being isolated and identified from *Azadirachta indica* and its relative, the chinaberry tree, *Melia azedarach* [9]. Several types of neem pesticides were used in Egypt, and only one compound (Achook) is registered by the Pesticides Committee, Ministry of Agriculture and Land Reclamation [14].

The journey to identify new anti-pathogenic materials from plants is an ongoing activity in the world and Egypt. By conducting a simple online search on Google scholar using the keywords "Natural Products as Sources for New Pesticides," more than 3,110,000 and 942,000 research articles hits were obtained for worldwide and

Egyptian scientists, respectively, which highlights the popularity of this research subject. The Egyptian researchers are engaged in studying and screening various plants, herbs, and trees for the identification of active components, but there is not a single article summarizing their work. Therefore, current chapter will track mainly the studies conducted by Egyptian researchers and will follow the success stories, if any, of the registration of acaricides, bactericides, fungicides, insecticides, herbicides, and/or nematicides from natural sources. Also, a comprehensive overview of the development and application of the nanoformulations in the pest management strategies will be reviewed.

2 Plants' Active Components as Pesticides

2.1 Acaricides and Miticides

Several natural products, materials, and tactics were used as acaricidal/miticidal alternatives. The intercropping of *Asparagus scandens* with sour orange seedlings *Citrus aurantium* significantly reduced the number of *Tylenchulus semipenetrans* larvae with no significant difference from Vydate, the synthetic acaricide [15]. Also, intercropping cucumber with *Plectranthus amboinicus* effectively controlled the eggs and movable stages of *T. urticae* [16]. Intercropping plant crops provide a natural trap for different pathogens because of the allelopathic effects that sometimes stimulates the host plant to produce anti-pathogenic chemicals and/or proteins.

Plant extracts and essential oils (EOs) were effective in controlling the acari with varying degrees of potency compared to synthetic acaricides. The alkaloids, trigonelline, choline, and hypaphorine, were the main active chemicals in *Abrus precatorius* seeds and showed great activity against *Tetranychus urticae* [17]. The cardiac glycosides, digitoxin, cardenolide, and azadirachtin that were extracted from *Digitalis purpurea*, *Calotropis procera*, and *Azadirachta indica*, were effective against larvae and adult stages of the camel tick, *Hyalomma dromedarii*, with comparable results to the commercial products [18]. The EOs of French lavender (*Lavandula officinalis*) exerted different degrees of toxicity to eggs and adult females of the predacious mites *Euseius yousefi*, *Amblyseius zaheri*, and *Typhlodromus athiase* [19]. Certain fractions of the chloroform extracts of leaves and root of *Hyoscyamus muticus* (Solanaceae) exhibited acaricidal activity against *T. urticae* because of the presence of the alkaloids, isofucosterol, scopoletin, and muticin [20]. The EOs of mattercary, fennel, caraway, garlic, cinnamon, chenopodium, and eucalyptus were highly potent against *T. urticae* [21].

Leaf extracts of *Artemisia judaica* showed acaricidal bioactivities against adult females and immature stage of *T. urticae* and its predator *Phytoseiulus persimilis* [22]. Also, the EOs of chamomile (*Chamomilla recutita*) were potent acaricides agents against *T. urticae* followed by marjoram (*Majorana hortensis*) and *Eucalyptus*, where the major components of *C. recutita*, after GC-MS analysis, were α-bisabolol oxide A (35.251%) and trans-β-farersene (7.758%), while the main components of *M. hortensis* were terpinene-4-ol (23.860%), *p*-cymene (23.404%), and sabinene (10.904%) [23]. The flavonoids of *Polygonum equisetiforme* (quercetin, avicularin, isoquercitrin, betmidin, and myricitrin) had acaricidal activity against *T. urticae*. Quercetin was the most toxic flavonoid when it was applied against the larvae and adults as leaf-dip [24]. The phytochemical content of the aerial parts *Ethulia conyzoides* was 3-O-acetyl lupeol, lupan-3-ol, ethuliacoumarin, and 7-O-methyl apigenin. The ethyl acetate and ethuliacoumarin were reported as potent acaricides to larvae and adults of *T. urticae* [25].

Another approach was the application of salts and inorganic acids, e.g., boric acid, ascorbic acid, and potassium sorbate, as pesticide alternatives against the *Polyphagotarsonemus latus* (Banks) mite and *Myzus persicae* (Koch) aphid on potato plants; the results were similar to that of the Ortus acaricide [26]. To the best of our knowledge, however, many research studies were conducted to find safe and effective chemicals to control mites and acari, not a single product was formulated for commercial use.

2.2 Bactericides and Fungicides

Several agents have been applied either alone or in combination with the synthetic bactericides and fungicides as synergistic agents. Induction of the plants' immune system (acquired or induced systemic resistance) was among the successful techniques. For instance, the application of indole acetic acid, kinetin, humic acid, nicotinic acid, salicylic acid, plant guard, eminent, planvax, and tilt showed promising degrees of controlling the rust disease caused by *Puccinia pimpinellae* on anise plants through the elevation of the plant defense system compared to ethephon [27]. Hydrogen peroxide, calcium chloride, and chitosan at 1.5 and 2% inhibited completely the growth and spore germination of *Botrytis cinerea*, *Rhizopus stolonifer*, *Penicillium digitatum*, and *P. italicum* on strawberry and navel orange [28]. The biological control agents *Trichoderma hamatum*, *Trichoderma harzianum*, and *Paecilomyces lilacinus* and the systemic defense inducers Bion (benzo(1,2,3) thiadiazole-7-carbothioic acid S-methyl ester) and salicylic acid (SA) were applied individually or as mixtures and showed increased protection of the cotton seedlings against *Fusarium oxysporum* and *Pythium debaryanum* under greenhouse and field conditions [29]. Pure grade of the EOs of cinnamon, clove, and thyme and the defense inducers (sodium bicarbonate, potassium bicarbonate, calcium chloride potassium monohydrogen phosphate, and humic and folic acids) (mixture, 1:1) showed moderate to high antifungal against *Sclerotinia sclerotiorum* and *S. minor* in vitro [30].

Foliar spray of calcium chloride (20 mM) with *Saccharomyces cerevisiae* 10×10^{10} cfu/mL (10 ml/L), chitosan (0.05 mM), and potassium bicarbonate (20 mM) mixed with thyme oil (5 ml/L) not just reduced the powdery and downy mildews and late blight diseases on cucumber, pepper, and tomato plants but also increased the yield [31]. Combining chitosan and the biological control agents, *Trichoderma harzianum*, *T. viride*, *Bacillus subtilis*, and *Pseudomonas fluorescens*, revealed antagonistic effects against *F. oxysporum radicis lycopersici*, *F. oxysporum lycopersici*, *F. solani*, *Rhizoctonia solani*, *Sclerotium rolfsii*, *Macrophomina phaseolina*, *Pythium* sp., and *Phytophthora* sp. [32]. El-Mougy et al. [33] reported that soil drenching with mixtures of humic and folic acids + furfural + *T. harzianum* and furfural + *T. harzianum* highly reduced the disease severity of root rot on cantaloupe. In another study, repetitive doses of 2,4-dichlorophenoxy acetic acid (2,4-D), abscisic acid (ABA), and H_2O_2 successfully increased peroxidase (POD), phenylalanine ammonia lyase (PAL), and polyphenol oxidase (PPO) enzyme activities and gene expression of potato cultivars and protected the plants against *Alternaria solani* [34].

The glucosides, simmondsin and simmondsin-2′-ferulate, were isolated from the seeds of jojoba plant (*Simmondsia chinensis*) and showed moderate to high antifungal activity against *Pythium debaryanum*, *F. oxysporum*, *R. solani*, and *Botrytis fabae* [35]. The sesquiterpene, artemisinin, was isolated from *Artemisia annua* L. and was more potent bactericide and fungicide compared to its semisynthetic derivatives: dihydroartemisinin, artemether, and artesunate against *Aspergillus flavus*, *A. solani*, *R. solani*, *F. oxysporum*, *Agrobacterium tumefaciens*, and *Erwinia carotovora* var. *carotovora* [36]. The chemical compositions of the EOs of *A. judaica*, *A. monosperma*, *Callistemon viminalis*, *Citrus aurantifolia*, *C. lemon*, *C. paradisi*, *C. sinensis*, *Cupressus macrocarpa*, *C. sempervirens*, *Myrtus communis*, *Origanum vulgare*, *Pelargonium graveolens*, *Rosmarinus officinalis*, *Syzygium cumini*, *Schinus molle*, *S. terebinthifolius*, *Thuja occidentalis*, and *Vitex agnuscastus* were identified by the GC-MS. The major constituents were limonene, α-pinene, 1,8-cineole, pulegone, γ-thujone, capillene, sabinene, α-phellandrene, 4-terpineol, *trans*-caryophyllene, and α-citronellol. These oils were effective against *A. tumefaciens*, *E. carotovora* var. *carotovora*, *A. alternata*, *Botrytis cinerea*, *F. oxysporum*, and *Fusarium solani*. But the oils were more potent against *E. carotovora* var. *carotovora* than *A. tumefaciens*. The oil of *T. occidentalis* revealed the highest antibacterial activity on *A. tumefaciens* and *E. carotovora* var. *carotovora*. The essential oil of *A. monosperma* was the most potent inhibitor against *A. alternata*, *B. cinerea*, *F. oxysporum*, and *F. solani* [37]. In another study, five *pseudo*-guaianolide sesquiterpenes (*neo*ambrosin, damsinic acid, damsin, ambrosin, and hymenin) were isolated from shoots of *Ambrosia maritima* and were effective against *A. tumefaciens* and *E. carotovora* with varying degrees. Neoambrosin showed the highest antibacterial activity among the tested sesquiterpenes [38].

Carnation, caraway, and thyme oils reduced the mycelial growth of *Alternaria solani* compared to the chemical fungicide Ridomil, but among the oils, the carnation oil had the strongest inhibitory effect [39]. The effectiveness of the EOs of cumin, basil, and geranium in control of cumin root rot compared to synthetic fungicides was investigated [40]. They reported that, in greenhouse and field studies, the EOs inhibited the growth of *F. oxysporum*, *F. solani*, *F. moniliforme*, *F. dimerum*, *F. equiseti*, and *F. lateritium*. On the other hand, it promoted the plant growth parameters (plant height, shoot fresh weight, root fresh weight and number of branches). Abdel-Kader et al. reported that the carnation, caraway, thyme, peppermint, and geranium EOs were effective inhibitors of the mycelial growth of

F. solani, *R. solani*, *Sclerotium rolfsii*, and *Macrophomina phaseolina* under in vitro conditions and completely inhibited the fungal growth at 4% concentration of carnation and geranium oils [41]. In another study, they reported that the EOs of lemongrass, thyme, and rose were potent inhibitors of the mycelial growth of *Aspergillus niger* (in vitro) and *Bacillus subtilis* (in the field as a soil drench treatment) [42].

The flavonoids, isoglabratephrin, (+)-glabratephrin, tephroapollin-F, and lanceolatin-A of *Tephrosia apollinea*, showed considerable antifungal activity against *A. alternata*, *Helminthosporium* sp., *Colletotrichum acutatum*, and *Pestalotiopsis* sp. in a concentration-dependent manner [43]. Moreover, spraying potato tubers with the EOs extract of *Pimpinella anisum*, as an emulsion, prior to *Ralstonia solanacearum* infection, protected tubers from any rot diseases [44]. The EOs of *Pinus rigida* and *Eucalyptus camaldulensis* showed antimicrobial effects against the hyphal growth of *Alternaria alternata*, *Fusarium subglutinans*, *Chaetomium globosum*, *Aspergillus niger*, and *Trichoderma viride*, and the major components in the *P. rigida* wood oil were α-terpineol (34.49%), borneol (17.57%), and fenchyl alcohol (14.20%), while the eucalyptol (60.32%), α-pinene (13.65%), and γ-terpinene (8.77%) were reported in the leaves of *E. camaldulensis* [45].

Solvent extractives (either inorganic, organic, or both) were extensively studied as potential bactericides and fungicides alternatives. Abdel-Monaim et al. [46] studied the aqueous and organic solvent of plant extracts of *Calotropis procera*, *Nerium oleander*, *Eugenia jambolana*, *Citrullus colocynthis*, *Ambrosia maritime*, *Acacia nilotica*, and *Ocimum basilicum* and fruit extracts of *C. colocynthis*, *C. procera*, and *E. jambolana* for protecting the lupine plants against damping-off and wilt diseases caused by *F. oxysporum* f. sp. *lupini*. In 2012, Bussaman and his team reported fungicidal actions of the ethanol, methanol, and chloroform extractives of leaves of *Piper sarmentosum* and *Metha cordifolia* against mycelium growth and spore germination of *Colletotrichum gloeosporioides* (the causal agent of anthracnose disease) [47]. The antibacterial efficiency of the chloroform extracts of the EOs of edible mushroom and garlic was compared with two bactericides (Streptrol and oxolinic acid) and two fungicides (mancopper and copper oxychloride) to control the potato soft-rot disease, *E. carotovora* var. *carotovora*. The in vitro results showed that both natural extracts and synthetic bactericides exhibited antibacterial activities particularly Streptrol and the chloroform extract of the mushroom. Mixing garlic oil (1 mg/ml) with Streptrol or oxolinic acid (at 0.05 mg/ml) synergized the inhibitory effect of both synthetic bactericides [48].

Various hexane and ethanol extracts of *Sesbania sesban* and *Cymbopogon citratus* and two algae species (*Spirulina platensis* and *Scendusmus* sp.) were screened as antifungal and antibacterial against *R. solani*, *Rhizopus stolonifer*, *F. oxysporum*, *A. niger*, *A. solani*, *Pythium debaryanum*, *B. cinerea*, *Penicillium digitatum*, *A. tumefaciens*, and *E. carotovora* var. *carotovora*. The ethanol extracts of *S. sesban* and *S. platensis* had the highest antifungal activity, while the ethanol extracts of *Scenedesmus* sp. and *S. sesban* had the highest antibacterial activity [49]. The antifungal activity indicated that methanol extract of the alga (*Ulva lactuca*) was the most potent against *A. niger*, *P. digitatum*, and *R. solani* compared to the acetone, chloroform, and petroleum ether extracts. The high potency of the methanol fraction was due to its richness with five major components: benzene,1-ethyl-2-methyl (1.98%), benzene,1,2,4-trimethyl (4.82%), palmitic acid (11.94%), 8-octadecanoic acid methyl ester (3.74%), and 1,2-benzene dicarboxylic acid, bis-(2-ethylhexyl) ester (65.42%) [50]. The water extract of *Asclepias sinaica* was effective as antifungal extract against *A. flavus*, *A. niger*, and *Fusarium moniliforme* [51]. The methanol and ethyl acetate extracts of seeds of *Abrus precatorius* had considerable control activity against *Pectobacterium carotovorum* subsp. *carotovorum*, *Ralstonia solanacearum*, and *Streptomyces scabies.* The work resulted in the identification of di-(2-ethylhexyl)phthalate as the major active component of both extracts and was responsible for the bactericidal effect obtained [52].

The EOs were rarely formulated to be used as commercial pesticides except in the case of the study of ElShafei et al. [53]. They prepared the EOs eucalyptus, linalool, and marjoram in several w/o/w double emulsion formulations with Span 80 and Tween 80 as emulsifiers and xanthan gum as a thickener. Successful formulations showed fungicidal activities against *B. cinerea*, *R. solani*, *F. solani*, and *Sclerotium rolfsii*.

2.3 Herbicides

The nonconventional control methods of weeds include soil solarization, biodegradable mulch, natural herbicides, hot water, agronomic practices, Fresnel lens, electrical weed control, lasers, competitive varieties, and stale seedbeds, which are considered as safe methods in the organic farming [54]. Corn gluten meal, vinegar (acetic acid), and citric acid were tested as promising non-synthetic herbicides to control weeds [54]. Hussein et al. [55] reported that cv. flax Giza 8 was the most suppressive to weeds, followed by cvs. Ariane and Belinka due to the allelopathic effects of these cultivars on weeds [55]. Purple nutsedge (*Cyperus rotundus*) foliage and tubers were tested for allelopathic potential against *Corchorus olitorius* (broad leave weed) and barnyard grass *Echinochloa crus-galli* (grass weed) in soybean. Analysis of shoots of *C. rotundus* revealed the presence of phenolic acids, caffeic, ferulic, coumaric, benzoic, vanillic, chlorogenic, and cinnamic, while tubers contained hydroxybenzoic, caffeic, ferulic, vanillic, and chlorogenic [56]. The *pseudo*-guaianolide sesquiterpenes, *neo*ambrosin, damcinic acid, damsin, ambrosin, and hymenidin, from the aerial parts of *Ambrosia maritima*, reduced the seed germination and seedling growth of wild oat, *Avena fatua*, where damsin was the most potent compound with seed germination percentage of 16.7% at 2 mM. The tested sesquiterpenes showed greater inhibitory effect on germination and growth of root and shoot than the reference herbicide, imazamethabenz [57]. The sesquiterpenes, artemisinin, dihydroartemisinin, artemether, and artesunate, showed effective herbicidal effects on seed germination and seedling growth of *Phalaris minor*, *Panicum repens*, and *Silybum marianum* [58].

2.4 Insecticides

Most of the studies on the use of plant extracts discussed mainly their potential insecticidal activities against various agricultural and health-related insects. For example, of the triterpenes, cardenolide glycosides and sterols compounds were isolated and identified from *Acokanthera spectabilis*, and it was reported that the triterpene friedelin is a potent antifeedant to the 3rd instar larvae of *Spodoptera littoralis* [59]. The glucosinolate, sinigrin, showed a repellent action against the leaf miners (*Liriomyza brassicae*) on cabbage plants [60]. The diterpenes, paraliane and jatrophene, of *Euphorbia paralias* were effective molluscicidal against the snail (*Biomphalaria alexandrina*) and antifeedants to the 3rd instar larvae of *S. littoralis*, respectively [61]. Also, the tetranortriterpenoid (limonoids) compounds (methylangolensate, methyl-6-hydorxyangolensate, and 3,7-dideacetylkhivorin) were isolated from *Khaya ivorensis*, *Chukrasia tabularis*, and *Swietenia mahogany* plants and exhibited antifeedant effects to the 3rd instar larvae of *S. littoralis*. The 3,7-dideacetylkhivorin exhibited a potent reduction of adult emergence, compared to the control. The most drastic effects were observed in the oviposition capacity and viability of eggs laid by females that fed as larvae on the treated diet with 1,000 mg/kg of 3,7-dideacetylkhivorin [62]. The alkaloids, haloxynine, piperidine, halosaline, anabasine, hordenine, N-methyltyramine, haloxine, and aldotripiperideine, were isolated from *Haloxylon salicornicum*. Haloxynine, halosaline, haloxine, anabasine, and smipine were the major alkaloids (5% of total alkaloids) in these plants and demonstrated great potential against insects [63]. The glucosides, simmondsin and simmondsin-2′-ferulate, were isolated from the seeds of jojoba plant (*Simmondsia chinensis*) and showed strong insecticidal and antifeedant activities against the 3rd instar larvae of *S. littoralis* [35].

The EOs, piperitone and *trans*-ethyl cinnamate of *Artemisia judaica*, showed antifeedant and antifungal activities against the 3rd instar larvae of *S. littoralis*. *Trans*-ethyl cinnamate was more toxic than piperitone [64]. Terpinen-4-ol and γ-terpinene were the identified components of the EOs of leaves of *Majorana hortensis* and were effective insecticides against *S. littoralis* and *Aphis fabae*. Even more, they synergized the profenofos and methomyl by two- to three-folds [65]. The major chemical constituents of extracts of *Zygophyllum coccineum* and *Mentha microphylla* were terpinen-4-ol (30.0%), γ-terpinene (11.3%), and *trans*-sabinene hydrate (10.8%), which showed varied insecticidal activity against the 4th instar larvae of *S. littoralis* and *A. fabae* [66]. Based on the LC_{25} and LC_{50} values, essential oil of *A. judaica* significantly reduced the F1 progeny production of the cowpea weevil, *Callosobruchus maculatus* (Fab.), compared to the control [67].

Several authors studied the use of natural extracts against the stored grain insects. Most of the studies reported significant effects, for example, Mohamed and Abdelgaleil reported potent contact and fumigant activity of *Mentha microphylla* oil against *Sitophilus oryzae* and *Tribolium castaneum* [68]. The essential oil extracts of fruits and leaves of *Schinus molle* were significantly deterred the *Trogoderma granarium*, and *Tribolium castaneum* insects and the monoterpenes were the dominant components in fruits and leaves of about 80.43 and 74.84%, respectively, while *p*-cymene was the major terpene in both oils [69]. Also, the powder and EOs of leaves of spearmint (*Mentha viridis*) protected wheat grains against *S. oryzae* under laboratory conditions [70]. Similarly, the activity of leaf powders and EOs of *Achillea biebersteinii*, *A. fragrantissima*, and *Ageratum conyzoides* against *S. oryzae*, *Rhyzopertha dominica*, and *T. castaneum* depended on the dose and the exposure period. When mixed with grains as powders, *A. biebersteinii* was the most effective in controlling the *S. oryzae*, while both *A. biebersteinii* and *A. conyzoides* powders and EOs (as fumigants) killed 100% of *R. dominica*. The biological activity of the EOs was due to the presence of biologically active secondary metabolites, where the EO of *A. fragrantissima* had *cis*-thujone (28.4%), 2,5-dimethyl-3-vinyl-4-hexen-2-ol (santolina alcohol) (16.1%), 3,3,6-trimethyl-1,5-heptadien-4-one (Artemisia ketone) (14.8%), and *trans*-thujone (12.5%). The major components of the oil of *A. conyzoides* were dimethoxy ageratochromene (precocene I) (68.3%), β-caryophyllene (10.4%), and α-humulene (4.6%), while the oil of *A. biebersteinii* had *cis*-ascaridol (33.8%), *p*-cymene (22.4%), camphor (8.6%), 1,8-cineole (6.3%), piperitone (5.4%), and carvenone oxide (4.3%) [71]. Also, when [72] repeated the work with the essential oils of *Achillea biebersteinii*, *A. santolina*, and *A. millefolium* against the *Tribolium castaneum*, the author reported a growth inhibition of the insect, but the *A. biebersteinii* oil showed the strongest insecticidal activity.

Studies on the solvent extracts reported that organic, polar, and essential oil extracts of seeds of the neem tree were effective against whiteflies insects (*Bemisia tabaci*) in a semi-field study [73]. The hexane extract of *Artemisia monosperma* significantly affected the biological and physiological characteristics of *S. littoralis* through the destruction of the epithelial and cell membranes of the midgut [74]. Field trials showed that the use of azadirachtin reduced the hatchability of eggs of the desert locust and could be an alternative to the chemical insecticides for control of grasshoppers [75]. Incorporation of Agrein (registered insecticide of *Bacillus thuringiensis*), petroleum oil (Sisi 6©), and the inorganic salt (barium nitrate) was an effective approach to control the sugarcane borers (*Sesamia cretica*) on maize and sorghum crops compared to methomyl under field conditions [76]. The pesticide, Ashock (a commercial product of neem), malathion, KZ oil, and Naterlo oil, were effective to control the *Ceratitis capitate* on guava and mandarin orchard by 66.58, 59.91, 53.08, and 45.52%, respectively [77]. Onion (*Allium cepa*), sweet basil (*Ocimum basilicum*), and cumin (*Cuminum cyminum*) oils decreased severely the consumption index and efficiency of conversion of digested and ingested food of the 3rd nymphal instars of the desert locust (*Schistocerca gregaria*) [78]. The foliar spray of essential oils of basil, citronella, geranium, garlic, and camphor, aqueous extracts of *Capsium annum* and intercropping of *Plectranthus amboinicus* were effective in controlling the whitefly (*Bemisia tabaci*), thrips (*Thrips tabaci*), and mite (*Tetranychus urticae*) [79].

The insecticidal activity of acetone, chloroform, ethanol, methanol, and petroleum ether extracts of the alga (*Ulva lactuca*) was tested against mosquito larvae (*Culex pipiens*), cotton leafworm (*Spodoptera littoralis*), and three phytopathogenic fungi, *A. niger*, *P. digitatum*, and *R. solani*. The results indicated that the acetone extract was the most potent fraction against *C. pipiens* and ethanol and chloroform extracts were active as larvicides to *S. littoralis*. The high potency of the methanol fraction was due to its richness with benzene,1-ethyl-2-methyl (1.98%), benzene,1,2,4-trimethyl (4.82%), palmitic acid (11.94%), 8-octadecanoic acid methyl ester (3.74%), and 1,2-benzene dicarboxylic acid, and bis-(2-ethylhexyl) ester (65.42%) [50]. The oils of *Artemisia monosperma*, *Schinus terebinthifolius*, and *Origanum vulgare* displayed high larvicidal activity against the West Nile vector. Also, the oils *A. judaica*, *Cupressus macrocarpa*, *Rosmarinus officinalis*, *Citrus limon*, and *C. aurantifolia* were potent fumigants against the adults of *C. pipiens*. These activities encouraged the use of essential oils as alternative mosquito control agents [80].

The Margosan-O, a commercial preparation of neem seed extract, was tested against the bean aphid *Aphis fabae* and compared with the German product Neem-Azal S. The Neem-Azal S had an effective deterrent action to the 2nd and 4th nymphal instars of *A. fabae* [81]. Spraying the cotton plant with 2.5% of the oil emulsion of the EOs of white mustard oil reduced egg deposition and egg viability of *S. littoralis.* Also, the moth longevity was significantly reduced, and females were more affected by the treatment than males [82]. The nimbecidine EC (a botanical insecticide that contains 0.03% azadirachtin; the limonoids, meliantriol, salannin, and nimbin; and some other terpenoids of neem tree (T. Stanes & Company Limited, India)); essential oils of *Brassica nigra*, *Boswellia carterii*, and *Nigella sativa*; and mineral oils, KZ oil 95% and Super Royal oil 85.7%, were effective against scale insects *Ceroplastes rusci* and *Asterolecanium pustulans* on fig trees [83]. Also, Salem et al. [84] went a step forward and prepared the essential oils of *Ambrosia maritima*, *Origanum minutiflorum*, *Cymbopogon nardus*, and *Cymbopogon citratus* as 3% emulsifiable concentrates (EC) and named them Demso, Oregacide, Citrocide, and Lemocide, respectively. They reported that Oregacide was effective scalicide against mango scale *Aulacaspis tubercularis*, yellow scale *Aonidiella citrina*, and acuminata scale *Kilifia acuminate.* Registration of one commercial product "Ashock" for the neem trees extracts by the Pesticide Committee, Ministry of Agriculture and Land Reclamation [14].

2.5 Nematicides

Several techniques including the natural extracts of plants, intercropping different crops, and salts and acids were applied as nematicide alternatives. Intercropping tagetes with tomato and the application of natural root exudates of tagetes reduced the population, galls on roots, and egg masses of *Meloidogyne javanica* [85]. Also, intercropping henna plant (*Lawsonia inermis*) with tomato plants significantly reduced the root gall numbers, the number of egg-laying females, and rate of the reproduction of *M. incognita* [86]. Also, planting the marigolds (*Tagetes erecta* and *T. patula*) or damsisa (*Ambrosia maritima*) with soybean (*Glycine max*) significantly reduced *Meloidogyne incognita* nematode numbers, the percentage of galls, developmental stages, and egg masses in roots and juveniles (J2) in soil [87].

The essential oils of many plants showed some degree of efficiency to control nematodes. EOs of *Mentha spicata*, *Thymus vulgaris*, *Majorana hortensis*, and *Mentha longifolia* were effective nematicide alternatives to *Meloidogyne incognita* [88]. Also, the aqueous extracts of leaves of basil (*Ocimum basilicum*), marigold (*Tagetes erecta*), pyrethrum (*Chrysanthemum cinerariaefolium*), Chinaberry (*Melia azedarach*), and neem seeds (*Azadirachta indica*) were effective in controlling the root-knot nematode *Meloidogyne incognita* [89]. Plant residues (dry leaves of fleabane, sugar beet, and mud sugar beet), bio-fertilizer (Nile fertile), and organic compost alone or in combination with the biocides Nemaless significantly reduced the number of nematode juveniles (J2) in soil and number of galls and egg masses in roots of *Meloidogyne incognita* [90].

Citric acid that was formulated as a soluble powder (90% SP) showed nematicidal efficiency to *Meloidogyne* sp. compared to the nematicide methomyl [91]. Application furfural with urea showed superior effects in controlling both *Fusarium solani* and *Meloidogyne incognita* relative to each of them and to the reference fungicide and nematicide [92]. Salicylic acid, acetylsalicylic acid (ASA), 3,5-dinitrosalicylic acid (DNSA), L-ascorbic acid (AA), oxalic acid, and citric acid were applied for managing *Meloidogyne incognita* on tomato plants under greenhouse conditions. The results showed that all tested organic acids reduced root galls and 2nd juvenile numbers in soil compared with control, except for DNSA and AA as a foliar application, which were more effective in reducing nematode galls than soil drench application. Foliar application of ASA caused a superior effect in the reduction of J2 in soil [93].

3 Nanotechnology in Pest Management

The problem with the traditional pesticides is the application of large volumes to effectively control different pathogens. Nano-sized formulations of pesticides would help to deliver the active ingredients to pathogens effectively in small quantities. Also, the slowly released nanoformulations efficiently prolonged the control approach and protected the pesticides from the harsh environmental conditions. Additionally, the safety index of the nanoformulations to the nontarget organisms is significant. The nanotechnology is being used in the manufacturing of nanosensors, functional nanocomposites, new product development, smart packaging, nano-pesticides, nano-fertilizers, plant growth promoters, and nanoparticle-mediated DNA (improvement of plants' traits against stress and disease) [94–99]. Currently, there are more than 8,048 patents that were registered as a sort of nano-pesticides including nanosuspensions, nano-solid dispersion, nanoemulsions, detection sensors, particulate delivery system, biochip substrates, and encapsulated pesticides [100].

Recently, about 2,312 research articles were released on detection and extraction of pesticides using nanotechnology and nano-pesticides formulations [101]. Major benefits of the application of the nanotechnology in the pest management programs are the increase of the bioavailability through the increased surface area, enhanced penetration inside the insect and plant waxy layers due to the small size, enhanced wetting and spreading properties, improved solubility, enhanced stability to environmental degradation (pH, temperature, and light), and long lasting in the pathogen environment through the control-released formulations [96, 102–106]. Such technology might be the magical solution to produce clean food and be used to develop safe, efficient, low-cost, reproducible, and environmentally friendly biological active materials against phytopathogens. For a better understanding of the applicability of nanotechnology in agriculture, a concise review is presented in the following section.

3.1 Nano-pesticides

Encapsulation of pesticides as nanoparticles, preparation of controlled-release nano-emulsions of pesticides, and nano-metallic-pesticides formulations are discussed. For example, encapsulation of Avermectin in porous hollow silica nanoparticles (NPs) with a shell thickness of 15 nm and a pore diameter of 4–5 nm protected the Avermectin from UV degradation and allowed its slow release for about 30 days instead of 6 h for the commercial Avermectin [107]. After formulating the herbicides 2,4-D and Picloram with hexagonal mesoporous silica NPs and carboxylic acid, they were released slowly into the environment [108]. The controlled-release nanoformulations of Imidacloprid, synthesized by encapsulating the insecticide with polyethylene glycol and aliphatic diacids, showed improved efficiency against many pests on different crops [109]. Paraquat encapsulated in AgNPs-chitosan had enhanced herbicidal activity against *Eichhornia crassipes* [110]. The nano-encapsulation of Temephos and Imidacloprid insecticides gave the same larvicidal effects on *Culex quinquefasciatus*, but the release of these insecticides into the mosquito environment was controlled, which provided a longer protection time [111]. Additionally, the encapsulation of 2,4-D herbicide into a nano-sized rice husk enhanced its herbicidal activity against the *Brassica* sp. and extended its release time in the environment [112]. Also, NPs of Prochloraz cross-linked with alginate protected it from UV degradation and the alkaline conditions and protracted its release for 60 days [96, 113].

Another formulation of the nano-pesticides is the nanoemulsions. Formulating β-Cypermethrin as nanoemulsions increased its stability and release time and reduced its rate of application compared to the commercial one [114, 115]. Bang et al. [116] coated the Etofenprox and α-Cypermethrin with chitosan. They reported that the chitosan-coated nanoliposomes were thicker and released over a longer period. Also, the nanoformulations of chitosan-coated Pyrifluquinazon increased its antifeedant effect to green peach aphid, *Myzus persicae* [117]. Moreover, preparation of Glyphosate Isopropylamine as nanoemulsion did not affect its herbicidal activity against *Eleusine indica* compared to the commercial Glyphosate but increased its penetration into the soil and decreased spray deposition [118]. The nanoformulation of Pyrifluquinazon loaded in chitosan 3,000 controlled its release and prolonged its activity up to 14 days. Also, NPs of chitosan nanocarrier and the metabolite from the fungi *Nomuraea rileyi* showed high pesticidal activity against *Spodoptera litura* [119]. The broad-spectrum fungicide Pyraclostrobin, when it was formulated in the chitosan-lactide copolymer NP, was more active against *Colletotrichum gossypii* [120]. The release time of the insecticide Fipronil was extended 3 days when prepared a biocompatible oil-core silica-shell nanocapsule emulsion [121]. The herbicide (Glyphosate) and the insecticide (Cypermethrin) were loaded in a magnetic nanocarrier (micro-nano pores of diatomite/Fe_3O_4) and coated by chitosan to control their release over time. The nanoformulations produced more persistent pesticides on the weeds' surface and in the pests' epidermis, slowly released, and showed greater efficacy against the pests [122].

Formulation of water-dispersible amorphous Permethrin NPs (~151 nm) showed higher larvicidal activity ($LC_{50} = 0.117$ mg/L) against *C. quinquefasciatus* than Permethrin ($LC_{50} = 0.715$ mg/L) [123]. Preparation of the insecticide Chlorfenapyr as dispersible silica-based nanoformulation increased its toxicity two times to the larvae of *P. xylostella* [124]. As well, the formulations of the insecticides as PEG-based amphiphilic copolymers NPs caused the release of the active ingredient slower than the commercial formulations, for example, β-Cyfluthrin [125], Carbofuran [126], Imidacloprid [109, 127], Thiamethoxam [128], and Thiram [129]. Saini et al. [130] reported the in vitro insecticidal activity of Pyridalyl-sodium alginate nanosuspension against larvae of *Helicoverpa armigera* was increased from two- to sixfolds as stomach poison compared to the commercial Pyridalyl.

Nanoparticle formulations were not only effective against the designated target but also safe to nontarget organisms and the environment. It was reported that the 24 h LC_{50} of Permethrin NPs microemulsion against *Aedes aegypti* (6.3 μg/L) was approximately threefolds less than the regular micro-particulate Permethrin (19.9 μg/L). Moreover, the nanoscale formulation did not show toxicity against nontarget organisms (*Escherichia coli* (ATCC 13534 and 25,922), *Bacillus subtilis*, *Lycopersicum esculentum*, *Cucumis sativus*, and *Zea mays*) [131]. The nanocapsules of poly(ε-caprolactone) with Ametryn and Atrazine had low toxicity to the beneficial alga *Pseudokirchneriella subcapitata* [132]. Also, the NP formulations of poly (ε-caprolactone) with Atrazine were effective to control the *Brassica* species and reduced the mobility of the herbicide in the soil, which reduced its harmful effects to the environment [133]. Herbicides as solid lipid nanoparticles (SLNs) were effective as pre- and postemergence treatment to *Raphanus raphanistrum* and did not affect plant growth of nontarget organism *Z. mays* [134].

3.2 Metallic Nanoparticles

Metallic nanoparticles offer dual-purpose materials for agriculture, where they would be applied as fertilizers and/or pesticides. Most metallic nanoformulations have been reported to increase plant growth characteristics and yield quantity and quality along with the eradication of pathogens. It enhances the plants' defense system via several mechanisms, i.e., increase stem and root growth, photosynthesis rate, and chlorophyll content, and enhances total nitrogen, ammonia, and oxygen. Additionally, they were reported as antibacterial, antifungal, antiviral, antiprotozoal, acaricidal, larvicidal, insecticidal, and anticancer agents. Therefore, metallic nanoparticles of, e.g., silver (Ag), copper (Cu), zinc (Zn), alumina (Al_2O_3), magnesium oxide (MgO), silica (SiO_2), zinc oxide (ZnO), and titanium oxide (TiO_2) are popular nanoparticle products all over the world [135].

Many minerals were atomized in the nano-form and been applied to control various types of pathogens, but the silver nanoparticles were the most studied one. A surplus of studies reported the potential and impact of AgNPs as anti-pathogenic agent including Jo et al. [136] who reported that AgNPs effectively controlled the pathogenic fungi on perennial ryegrass (*Lolium perenne*). Also, the AgNPs inhibited the activity of *Colletotrichum* spp. (anthracnose pathogen) [137] and powdery mildew on cucumber and pumpkin [135] in field trials. The in vitro assays showed strong inhibitory effects of AgNPs against various fungal plant pathogens: *A. alternata*, *Sclerotinia sclerotiorum*, *Macrophomina phaseolina*, *Rhizoctonia solani*, *Botrytis cinerea*, *Curvularia lunata* [138], *Fusarium oxysporum* [139], *Colletotrichum coccodes*, *Monilinia* sp., and *Pyricularia* sp. [140], *Bipolaris sorokiniana* [141], fungi-like *B. sorokiniana* and *Magnaporthe grisea* [136], *Fusarium* sp. and *Phoma* sp. [142], and *Alternaria solani*, *Cylindrocarpon destructans*, *Fusarium* sp., *Pythium aphanidermatum*, *Pythium spinosum*, *Cladosporium cucumerinum*, *Didymella bryoniae*, *Glomerella cingulata*, *Monosporascus cannonballus*, and *Stemphylium lycopersici* [143].

The AgNPs were prepared with pesticides to increase their activities and reduce the amounts required to control different pathogens, for example, AgNPs with the fungicide Fluconazole and hyphal filtrate of *Alternaria alternate* were effective against *Phoma glomerata*, *Phoma herbarum*, *Fusarium semitectum*, *Trichoderma* sp., and *Candida albicans* [142, 144]. Silver nanoparticles have been found to be effective against numerous species of plant pathogenic bacteria, including *E. coli*, *Enterococcus faecalis*, *Staphylococcus* (*aureus* and *epidermidis*), *Vibrio cholera*, *Pseudomonas* (*aeruginosa*, *putida*, *fluorescens*), *Shigella flexneri*, *Bacillus* (*anthracis*, *subtilis*, and *cereus*), *Proteus mirabilis*, *Salmonella enteric*, *Micrococcus luteus*, *Listeria monocytogenes*, and *Klebsiella pneumoniae* [145–147]. Also, AgNPs were also effective against vancomycin-resistant *Enterococcus* and the fungi *Candida albicans*, *Aspergillus niger*, and *Trichophyton mentagrophytes* [145, 148].

Similarly, The CuO, Cu_2O NPs, and Cu/Cu_2O nanocomposites were effective fungicide alternatives to *Phytophthora infestans* [149] and *Phoma destructiva*, *Alternaria alternata*, *Curvularia lunata*, and *Fusarium oxysporum* [150]. Similarly, the Cu-chitosan NPs were effective in controlling *A. alternata*, *M. phaseolina*, and *R. solani* [151] and *Alternaria solani* and *Fusarium oxysporum* [152]. When CuNPs were coated with dextrose, dextran, and β-cyclodextrin (sugar-capped CuNPs), it revealed more stability and significantly reduced the disease severity of *Rhizoctonia* *solani* [153]. Also, Cu-Ag NPs revealed promising results against the white-rot (*Trametes versicolor*) and the brown-rot (*Poria placenta*) fungi [154].

Silica nanoparticles were reported as potent and safe pesticides against the fungi, *R. solani*, *B. cinerea*, *M. grisea*, *Pythium ultimum*, and *Colletotrichum gloeosporioides* [155], the stored grain insects *S. oryzae* and *T. castaneum* and two field pests *Lipaphis pseudobrassicae* and *S. litura* [156], and the mosquito vectors *Anopheles stephensi*, *Aedes aegypti*, and *Culex quinquefasciatus* [157]. Nanocomposites of silver-silica revealed antimicrobial activities to *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas fluorescens*, *Salmonella enterica*, *Enterococcus faecalis*, *Bacillus cereus*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Candida albicans*, and *Aspergillus niger* [158]. The SiO_2-Ag nanocomposites were an effective antibacterial agent against *Xanthomonas oryzae* pv. *oryzae* on rice [159].

Wani and Shah reported a high inhibition rate of the germination of spores of *Alternaria alternate*, *F. oxysporum*, *Rhizopus stolonifer*, and *Mucor plumbeus* after the treatment with ZnO NPs and MgO NPs [160]. The Ag, ZnO, Mg, Si, and TiO_2 nanoparticles suppress crop diseases directly, through antimicrobial activity [161]. Polyvinylpyrrolidone-capped Mn- and Fe-doped ZnO nanocomposites exhibited a boosted antimicrobial activity to fungi and gram-negative and gram-positive bacteria [162]. Hoseinzadeh et al. reported an antifungal inhibition of *Fusarium graminearum* and *Fusarium oxysporum* within 1 and 2 h of application of the Fe_3O_4/ZnO/AgBr nanocomposite [163]. The silver-dsDNA-graphene oxide (Ag-dsDNA-GO) nanocomposites reduced the disease severity of the copper fungicide-tolerant *Xanthomonas vesicatoria*, *X. euvesicatoria*, and *X. gardneri* strains on tomato plants compared with copper-Mancozeb [164]. MgO, TiO_2, and ZnO NPs had antifungal activity to *Fusarium oxysporum* s. sp. *betae*, *Sclerotium rolfsii*, and *Rhizoctonia solani* on sugar beet [165]. Chitosan-copper nanocomposite (Cu@Chit NCs) was an effective antifungal agent to sclerotium-forming plant pathogenic fungi *Sclerotium rolfsii* and *Rhizoctonia solani* [166].

The nanostructured alumina dust (Al_2O_3) showed significant insecticidal activity on the stored insect pests *Sitophilus oryzae* and *Rhyzopertha dominica* [167, 168]. Shenashen et al. [169] manufactured mesoporous alumina-silica nanoparticles. They reported that it was effective against *Fusarium solani* under laboratory and greenhouse conditions [169]. Also, Shenashen et al. [169] showed that ZnO NPs inhibited the growth of *Botrytis cinerea* (63–80%) and *Penicillium expansum* (61–91%) [170]. The ZnO NPs exhibited high efficacy against many bacterial and fungal pathogens, *Staphylococcus aureus*, *Serratia marcescens*, *Proteus mirabilis*, *Citrobacter freundii*, *Aspergillus flavus*, *Aspergillus nidulans*, *Trichoderma harzianum*, and *Rhizopus stolonifer* [171]. Also, Jayaseelan et al. [172] demonstrated that ZnO NPs suppressed the growth of the bacteria *Pseudomonas aeruginosa* and fungi *A. flavus*. The rock powder and zinc oxide nanoparticles were potent insecticides against *S. oryzae* with respect to mortality rate and progeny of adults [173]. ZnO NPs reduced the growth of *Fusarium graminearum* in the mung bean broth agar by 26% [174] and inhibited the growth of *Staphylococcus* *epidermidis* among other microbes [175]. Both CuO and ZnO NPs had antimicrobial effects against the soilborne plant pathogens: *Pythium ultimum* and *P. aphanidermatum* [176].

Also, the titanium oxide nanoparticles (TiO_2NPs) showed great potential as agricultural amendments, due to both their photocatalytic and antimicrobial properties. In a field study, Cui et al. [177] showed that TiO_2NPs reduced the disease severity of *P. syringae* pv. *lachrymans* and *P. cubensis* on cucumber plants by 69 and 91%, respectively, and increased the photosynthetic rate by 30% [177]. Paret et al. [178, 179] showed that after the photoactivation of TiO_2NPs, it controlled the bacterial spot (*Xanthomonas* sp.) on rose and tomato plants as efficient as done by the conventional bactericide.

The toxic mechanism of metal nanoparticles and nanocomposites is not fully understood, but it was assumed to be similar to the silver toxicity. Generally, it was assumed that Ag^+ interacts with the disulfide or sulfhydryl groups of different enzymes. Then it causes structural changes that lead to disruption of metabolic processes and finally cell death. Specifically, the increased surface area and increased potential for the release of Ag^+ [158] and generation of reactive oxygen species (ROS) change the membrane permeability, interaction with proteins and disruption of their regular function, and interference with DNA replication, causing DNA damage [147, 156, 180]. In other words, the AgNPs caused the toxic action against the target pathogen through damaging the cell membrane leading to intracellular ion efflux, which result in cell death [135, 136]. He et al. [170] reported a systemic disruption of cellular function within the pathogens. The accumulation of AgNPs in the cell nuclei interacts with the DNA and might lead to cell death [181]. Results of several research studies revealed that AgNPs and Cu@Chit NCs cause shorten and condensed hyphae, cell plasmolysis, increased vacuolization, collapsed cytoplasm, condensed mitochondria, nuclear deformation, condensation and fragmentation of chromatin, and creation of apoptotic bodies [166, 182, 183].

3.3 Green Synthesis of Nanomaterials (Microbe- and Plant-Mediated Nanoparticles)

Nanoparticles of natural materials such as enzymes, polysaccharides, plant extracts, and microorganisms or their extrudes showed increased toxicity to target pests [184]. Garlic essential oil coated in polyethylene glycol (PEG) NPs was successful control agent against *T. castaneum* for 5 months after the application due to the slow release of the active components [185]. Spray-dried powder of the colloidal suspension NPs of the extracts of neem (*Azadirachta indica*) showed 100% larval mortality against *P. xylostella* [186]. The nanoencapsulation of the EOs of *Carum copticum* showed an antifeedant activity to *Plutella xylostella* larvae. It significantly decreased the relative consumption rate, relative growth rate, the efficacy of conversion of ingested food, and digestibility after 72 h of feeding [187]. The volatility (instability) and biological activity of thyme EOs to the *Aspergillus flavus* fungus were improved significantly through its encapsulation in chitosan-benzoic acid nano-gel [188].

Nanoparticles of metals and microorganisms and their filtrates showed increased toxicity and elevated control levels to pathogenic pests. Silver nanoparticles of *Trichoderma viride* showed synergistic effect of the antibiotics (ampicillin, kanamycin, erythromycin, and chloramphenicol) against *Salmonella typhi* (gram-ve) and *E. coli*, *Staphylococcus aureus*, and *Micrococcus luteus* (gram+ve) bacteria [146] and were effective against *R. solani*, *Fusarium proliferatum*, *B. cinerea*, and *F. oxysporum* [189]. The formulation of AgNPs with the aqueous extract of the filamentous fungus *F. oxysporum* had antifungal activities against pathogenic yeasts *Candida* and *Cryptococcus* [190]. Also, the AgNPs with *Pseudomonas aeruginosa* showed varying degrees of inhibition of gram-ve and gram+ve bacteria, but it was more effective to the gram-ve ones [191]. The myco-synthesized AgNPs with the hyphal filtrate of *Alternaria solani* were a potent fungicide to different pathogenic isolates of the same *A. solani* fungus [181]. In another study, silver nanoparticles that were synthesized using the fungi *Beauveria bassiana* showed mosquitocidal activities against larval instars of *Aedes aegypti*, *Anopheles stephensi*, and *Culex quinquefasciatus* and antibacterial effects against *Escherichia coli* and *Staphylococcus aureus* [192]. Nano-chitinases were prepared by immobilizing *Bacillus thuringiensis* chitinase Chi9602 on nano SiO_2 (SNPCs). The SNPCs were characterized by good dispersibility and UV resistance and increased storage stability, wide pH tolerance, and thermostability. Moreover, SNPCs exhibited an excellent nematicidal activity to *Caenorhabditis elegans* under laboratory conditions [193]. The AgNPs were biosynthesized using the extracellular filtrate of *Aspergillus foetidus*. These formulations inhibited the growth of *A. foetidus* remarkably [96, 105].

The potency of natural extracts was enhanced by synthesizing the natural extracts of plants into nanoparticles. The aqueous leaf extract of *Nelumbo nucifera* was synthesized as AgNPs and was toxic to the 4th instar larvae of *A. subpictus* and *C. quinquefasciatus* [194]. Also, AgNPs of the aqueous leaf extracts of *Pedilanthus tithymaloides* showed anti-developmental activity against the 4th larval instars of *A. aegypti* [195]. The AgNPs of *Sida acuta* leaf extract gave greater toxicity against *C. quinquefasciatus*, *A. stephensi*, and *A. aegypti* compared to the control [196]. Formulations of α-pinene and linalool with silica NPs boosted up their antifeedant potential against tobacco cutworm (*S. litura*) and castor semilooper (*Achaea janata*) with improved shelf life of these EOs [197]. Also, AgNPs were prepared with plant extracts, for example, the AgNPs of the leaf extract *Aloe vera* had great antifungal activity against *Rhizopus* sp. and *Aspergillus* sp. [198]. The EOs of *Ageratum conyzoides*, *Achillea fragrantissima*, and *Tagetes minuta* that were formulated as nanoemulsions showed increased toxicity against larvae and adults of the cowpea beetle, *Callosobruchus maculatus* [199].

Also, when the *Azadirachta indica* extract was prepared in the AgNPs formulation, it showed effective control of the mosquito (*C. quinquefasciatus*) [200]. The EOs of *Achillea biebersteinii*, *A. fragrantissima*, *A. santolina*, and *A. millefolium* plants were formulated as nanoemulsions. The nanoformulations showed improved antimicrobial activity against *Staphylococcus aureus*, *Listeria monocytogenes*, *E. coli*, *Pseudomonas aeruginosa*, and *Salmonella enteritidis* [201]. The Ag nanoformulations of petroleum ether, ethyl acetate, and ethanol extracts of *Urtica urens* showed increased activity against root-knot nematode *M. incognita* compared to the natural extracts. Moreover, the Ag-petroleum ether formulation showed similar nematicidal effects to the Ag-Rugby nanoparticles and the nematicide Rugby against the invasive *M. incognita* [202].

The metal oxide nanoparticles (SiO_2, TiO_2, and ZnO NPs) regulated the discharge of methyl eugenol (ME) from the lure dispensers in the mango orchards; this controlled-release of the active ingredient prolonged the control to *Bactrocera dorsalis* [203]. The AgNPs of the methanolic root extracts of *Diospyros sylvatica* showed efficient activity against the gram+ve; *Bacillus subtilis*, *B. pumilus*, *Streptococcus pyogenes*, *Pseudomonas aeruginosa*, and *Staphylococcus aureus* and the gram−ve; *Escherichia coli*, *Klebsiella pneumoniae*, and *Proteus vulgaris* and the fungi; and *Aspergillus niger*, *Penicillium notatum*, *Aspergillus flavus*, *Saccharomyces cerevisiae*, and *Candida albicans* [204]. The leaf extract of *Ginkgo biloba* was used to synthesize AgNPs, which inhibited the growth of *Setosphaeria turcica* [205]. The water extract of dandelion (*Taraxacum officinale*) was prepared in silver nanoparticles, and its antimicrobial activity against *Xanthomonas axonopodis* and *Pseudomonas syringae* was remarkably amplified [206].

4 Myth or Real Situation of Using Natural Extracts and Nanoparticles in Pest Management

Internationally, plant products (EOs and other compounds such as chitin and chitosan) are known as biochemicals, which are labeled as biopesticides. The other categories of biopesticides are microorganisms, semiochemicals (mostly insect pheromones), and plant-incorporated protectants (PIP; genetically modified plants). About 1,400 biopesticides are available in the market worldwide [207]. The EU authority approved about 68 biopesticides including 11 biochemicals, and the USA registered 202 products including 63 biochemical products [208]. Moreover, the biopesticides sector is growing rapidly, where the annual growth rate of used products was 16% compared to 3% for synthetic pesticides with an expected global market of US$10 billion by 2017 [208]. In Egypt, azadirachtin and the EO of orange (d-limonene) are registered and sold in the market under the names Ashock (insecticide) and Prev-AM (fungicide), respectively [14].

The global market of biopesticides is predicted to robust in the coming years because of increased public awareness about the safe and organic agriculture. Especially, the EU and US authorities considered these products as low risk to people, wildlife, and the environment. An encouraging point is the registration of plant products in the form of botanical pesticides might be easier compared with the synthetic pesticides. If the botanical products contain only one active ingredient, the registration is straightforward. The problem occurs when there is a mixture of components in the products and safety data to people, animals, wildlife, and environment need to be presented.

Similarly, nanotechnology is promising to improve crop production, water quality, nutrition, packaging, and food security. Nanotechnology might be a breakthrough in improving plant nutrient use efficiency through nanoformulation of fertilizers, surveillance and control of pests and diseases using the nanosensors, and development of new-generation safe and efficient pesticides. Yet, the nanotechnology applications in agriculture could be successful if greater scientific sophistication on toxicology and analysis are available for successful implementation.

The global market for nanomaterials production and consumption is increasing irrespective of the potential risk to human, plants, animals, wildlife, and the environment. There is a general agreement among the scientific community that there is inadequate information available about the fate and performance of these materials in the environment. Also, the regulations for nanoparticles use as agrichemicals can be still elusive. In Egypt, handful of commercially available nano-fertilizers are sold (e.g., NanoMobo Plus, GeoLife products (Vigore, CAB, and Spider), and Esterna NanoCair). Worldwide, the market of nano products is increasing exponentially. Several nanomaterials were patented and available in the USA as pesticides such as the silver-silicon nanocarrier (patent # US0225412-A1), HeiQ AGS-20 (silver-silica nanocomposite) produced by HeiQ Materials Company, and Nano-Argentum10 (nano-Ag; antifungal and bug repellent) from NanoSys GmbH company [99, 209]. Still, the safety of these compounds must be addressed extensively.

5 Summary and Conclusions

The application of natural origin with and/or without the nano-sized preparations would offer crop protection programs with materials that are active under various environmental conditions, reach the noxious pathogens, kill the pest effectively, safe to plants and mammals, cost-effective to manufacture, have varying mode of action, and provide economic returns and social benefits. However, an increasing attention must be devoted to the impact of risk factors associated with their usage on the environment and possible adverse effects on nontarget organisms and mammals. Nanoparticle formulations of pesticides, natural chemicals, and/or microorganisms or their cell constituents have demonstrated greater efficiency than commercial counterparts. Research in polymer-based formulations (nanoemulsion, nanoencapsulation, etc.) is rising, while research on the application of classical nanoparticles (nano-metallic) is slowing down for plant protection purposes. Nano-polymerization models might be promising for the delivery of the active ingredient to the target and are thus expected to receive the most attention in the future. Moreover, the lack of knowledge on the efficacy of nano-pesticides in field trials would encourage more field experiments. The development of nano-pesticides ought to be very beneficial in a way to attract the attention of pest management enterprises in order to revolutionize this industry.

6 Future Aspects

A plethora of studies reported on the efficacy of natural extracts and nano-formulations as pesticide alternatives. But, more research is needed on the risk associated with the applicability of these materials and specific mode of action of these materials to phytopathogenic pests and nontarget organisms. Incorporation of plant metabolomics, proteomics, and genomics in the study of botanical products and nanomaterials might speed up this work exponentially. More importantly, the collaboration between biology, chemistry, and pest management researchers is a must for standardization and maximization of extraction, purification, derivatization, and synthesis of such biologically active components and study their toxic effects for humans and beneficial organisms.

The majority of findings in the current chapter about the potential use of botanical pesticides and nanotechnology in agriculture is still at the experimental level, and very limited steps were pursued toward production or development commercial products. Several factors hinder such advancement either in Egypt or Worldwide; establishment of real links between industry and researchers or research institutions, scarcity or lack of adequate investments for researchers to prepare their products commercially, lack of launch of directed-companies toward the manufacture of promising, safe to the environment, and effective natural components as pesticides, and more importantly, the lack of Governmental regulations on the use of natural products and nanoparticles in pest control programs.

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Biological Pest Control for Sustainable Agriculture in Egypt

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Abstract Biological control is the use of beneficial organisms (predators, parasitoids, or pathogens) to decrease the population density of pest organisms (insects, mites, or plant pathogens). It is a main component of sustainable agriculture which is a system for maintaining the production on the long run without degrading the environmental resources. With the increased consciousness about the hazards of traditional chemicals in agriculture, it was noticed a remarkable decrease in the use of pesticides and an increase in the use of biological control agents (natural enemies). Biological control in any country depends on many factors, of the top importance are three namely: an abundance of natural enemies in the country, mass production, and field application of these natural enemies for the pest control. Egypt, like many other countries, has the potentiality to have a biological control industry. In this chapter, we discussed the status and potential of biological control in sustainable agriculture in Egypt through studying the abundance, the mass production, and the field application of natural enemies. Studied natural enemies included parasitoids, predators, predatory mites, and entomopathogenic nematodes.

Keywords Biological control, Entomopathogenic nematodes, Insect predators, Parasitoids, Predacious mites, Sustainable agriculture

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1 Introduction

Egypt is a populous country of about 90 million people living near the banks of the Nile River in an area of about 5% of its whole 1 million km^2 area. The large desert areas are mostly inhabited. The total fertile area is about 3.3 million ha of which 25% is reclaimed from the desert. Agriculture contributes over 13% of the Egyptian gross domestic product (GDP) and over 30% of employment opportunities. More than 57% of Egyptians live in rural areas. That means enhancing sustainable agriculture and rural development should be an engine for the socio-economic development [1]. Agricultural production has to increase by 7% by 2050 to face the population increase [2]. This production increase should be achieved in a system that preserves the environment and limits the use of pesticides and undesirable chemicals in agriculture. Sustainable agriculture is a system for maintaining production in the long run without degrading the natural resources by using low-input technologies. These technologies should improve soil fertility, enhance biological pest control, maximize recycling, etc. [3]. Sustainable agriculture has been neglected and suffered from limited adoption [4]. Integrated pest management programs of Ministry of Agriculture and Land Reclamation in Egypt avoid using chemical pesticides except in case of necessity using selective pesticides at optimal concentrations and time to protect the natural enemy population in Egyptian fields [5].

"Biological control can be effective in all types of agricultural systems, including organic, sustainable, and conventional agriculture" [6]. Biological control is a natural process that plays an important role in the suppression of pests in field crop, vegetable, and orchards [7–9]. It is the use of a living organism (a predator, a parasitoid or a pathogenic) to decrease the population density of another organism (for example, an insect, a mite, or a plant pathogen). A lot of the best examples of biological control proceed completely unnoticed by the farmer, simply because both the pest and its natural enemies coexist at such low densities that there is no perceptible problem in the crop, even though the pest is present [10, 11]. In short, whenever biological control has a role in pest population reduction, pest control decisions should be weighted by considerations of how natural enemies will be impacted, and what tactics might be practicable to conserve and maximize the efficacy of natural enemies [12]. It is generally approved that integrated biological control is the preferred approach for realizing the sustainable agriculture. Biological control is self-sustaining, nonpolluting, and cheap. Success in biological control of agricultural pests has many ecological, economic, social, and environmental positive impacts. It is an alternative to broad-spectrum and persistent pesticides as well as to genetically engineered resistance in crops [13].

Biological control industry in a given country depends on several factors including the highly qualified personnel, the infrastructure, the equipment, and the market. Also of the most important factors are the three pillars of biological control industry, namely (1) Abundance of the natural enemies in the native environment where they can be used for achieving the sustainable management of the target pests. (2) The possibility of mass producing the natural enemies either in vivo or in vitro to meet the needs of the biopesticide market. (3) The field application technology and measures of success in the biological control process.

The objective of this chapter is to discuss the status and potential of biological control in sustainable agriculture in Egypt through monitoring the abundance of natural enemies, the mass production, and the field application of these natural enemies. Studied natural enemies include (a) Parasitoids and predators, (b) Predatory mites, and (c) Entomopathogenic nematodes.

2 Background

2.1 Definition of Sustainable Agriculture and Biological Control

Sustainable agriculture is a system for maintaining production in the long run without degrading the natural resources by using low-input technologies [3]. These technologies should improve soil fertility, enhance biological pest control, maximize recycling, and so on. In another definition, sustainable agriculture is an integrated system of the agricultural practices in a specific site that is lasting over the long term. This system should satisfy human food and fiber needs, enhance environmental quality, and efficiently use the non-renewable resources [1, 3].

Biological control, where natural enemies are periodically distributed, is commercially applied over large areas in many countries. Initially biological control was used to control insect pests that had become resistant to pesticides. Now it is applied for reasonable cost/benefit ratio which is comparable with conventional chemical pesticides. More than 125 species of natural enemies are commercially used for biological control worldwide [14]. Biological control can be applied either in open fields, in case of crops that are attacked by a few pest species, or in greenhouse crops. It has no phytotoxic effects on young plants, flowers, or premature fruits. Biological control can be effective in all types of agricultural systems: organic, sustainable, and conventional [6].

2.2 History of Biological Control

The history of biological control may be considered from Egyptian records of 4,000 years ago where domestic cats were depicted as useful in rodent control. With the development of sophisticated agriculture, the Chinese citrus growers placed nests of predaceous ants in trees where the ants fed on foliage feeding insects. Insect parasitism was recognized in 1602 by the Italian Aldrovandi who observed the cocoons of *Apanteles glomeratus* being attached to larvae of *Pieris rapae*. By 1762 the first successful importation of an organism for biological control was the introduction of the mynah bird from India to the island of Mauritius for locust control. Most biological control agents, including predators, parasitoids, and insect pathogens at work in the agricultural environments are naturally occurring ones, which provide excellent regulation of many pests with little or no assistance from humans [9, 10, 15–19]. The natural existence of biological control agents is one reason that many plant-feeding insects do not become economic pests. There is a great potential for increasing the benefits from natural enemies, through the elimination or reduction of the use of chemical pesticides [20].

2.3 Abundance of Natural Enemies

There are natural enemies in nature, and they prevent some species from population outbreaks. This is widely identified as a fact, but it is a phenomenon that cannot be easily explained from an ecological point of view. Natural enemies definitely eat/parasitize their preys/hosts.

Egg parasitoids, by definition, are those that attack and complete their development within a host egg. They may be either solitary or gregarious, but in all cases, they prevent the host egg from hatching and completing its development (Fig. 1). *Trichogramma* species being abundant in all inhabiting continents were chosen for commercial production and field application worldwide.

Predatory mites act as an important biological control agents of small arthropod pests such as other mite pest groups, whiteflies, and thrips. According to van Lenteren [21], Acari is the second biggest group (after Hymenoptera) of natural enemies used commercially.

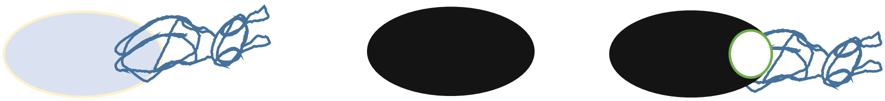

Fig. 1 Life cycle of *Trichogramma* species

Phytoseiids are widely used in biological control programs [22, 23], these predatory mites can reduce the population of spider mite pests under the economical damage levels in some agricultural ecosystems; its development depends on the type of food, temperature, and humidity. It is found that where the predatory mites are easily found, then the incidence of pest damage is decreased.

Entomopathogenic nematodes (EPNs) in families Steinernematidae and Heterorhabditidae are lethal microscopic roundworms associated with symbiotic bacteria in the family Enterobacteriaceae (genera Xenorhabdus and Photorhabdus). EPNs are effective in controlling a variety of economically important pests. EPNs have recently become a main component of biological control of insect pests so that it ranks #2 in the market of bioinsecticides after the entomopathogenic bacterium, *Bacillus thuringiensis*. The only free-living stage of the nematode is the infective juvenile (IJ) which is capable of actively seeking out hosts [24]. Following entry through natural body openings, and in some cases through the cuticle, the IJs release the symbiotic bacteria into the insect hemocoel [25]. The bacteria then multiply rapidly, killing the host within 1–2 days. EPNs complete 1–3 generations in the host cadaver and new infective juveniles are produced as food resources are depleted. Nematodes feed on host tissues and bacterial cells and complete their life cycle in 7–12 days (Fig. 2). Huge numbers of IJ then emigrate from the insect cadaver looking for surviving victims. Thus, EPNs have potential to recycle and provide long-term pest control.

2.4 Mass Production of Natural Enemies

Mass production of natural enemies involves the production of millions of insects (host and natural enemy), with the objectives of controlling pests. Insect production that can accomplish goals at an acceptable cost/benefit ratio, in numbers exceeding from 10 thousand to 1 million times the average productivity of a population of native females; Systematic, automated activity conducted in integrated facilities, to produce a relatively large supply of insects for distribution. Mass rearing is started from smaller-scale or research rearing (conducted by one or two people), or intermediate-sized rearing, upon which basic research about the target (often an agricultural pest) and the natural enemy (parasitoid or predator) are conducted.

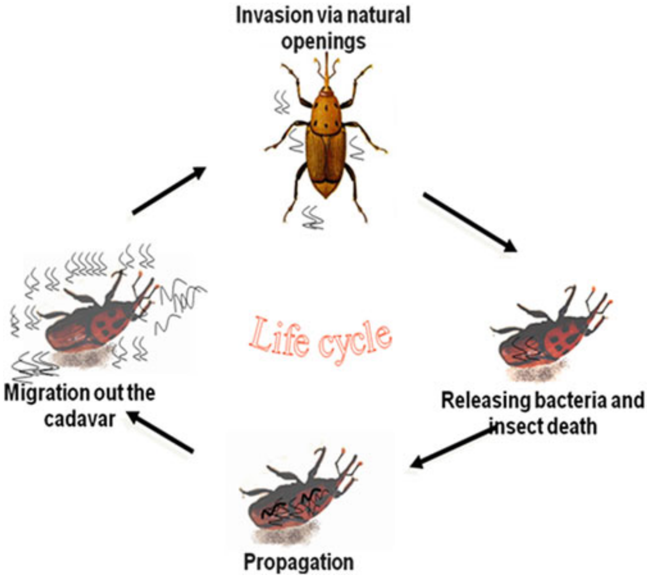

Fig. 2 Life cycle of entomopathogenic nematodes

Therefore, to produce natural enemies, two species have to be reared, the pest and the natural enemy. The potential for rearing a large number of natural enemies increased as artificial diets began to be developed since the 1960s, with emphasis on artificial diets for Lepidoptera, Coleoptera, and Diptera.

There are more than 200 known species of *Trichogramma* around the world, but only 19 species have been mass reared for use in augmentative biological control [26]. In fact, for many years, only one or two species dominated field trials and commercial applications in each of the major continents, *T. chilonis* in Asia, *T. dendrolimi* in China, *T. evanescens* in Egypt, and Europe and *T. pretiosum* in both North and South America [14, 27–30].

These species appear to have dominated *Trichogramma* trials based primarily on ease of rearing on the factitious stored product [31]. While commercial viability is clearly enhanced by the ease of rearing and a broad host range of target pests, technical effectiveness can be an important trade-off for this strategy.

The phytoseiid mite *Phytoseiulus persimilis* was successfully mass rearing on the two-spotted spider mite, *Tetranychus urticae*, whereas *P. persimilis* had great population growth rate comparative to its prey mite [32]. Additionally, among the most important phytoseiid mites that sold commercially and used as bio-control agents of greenhouse pests were *Neoseiulus californicus*, *N. barkeri*, *N. cucumeris*, *N. fallacis*, *Iphiseius degenerans*, *Galendromus helveolus*, and *G. occidentalis* [33, 34].

Entomopathogenic nematodes could be produced through either in vivo or in vitro procedures. For laboratory and semi-field experiments, in vivo production should be the suitable technique. When it comes to using of EPNs for large scales, in vitro production is currently the economically practical strategies to supply EPNs at rational costs.

2.5 Field Application of Natural Enemies

One goal in pest control is to develop methods that suppress pests without harming other organisms. An ideal method would be to augment organisms to control insects. This can be accomplished by mass releasing the natural enemies for controlling agricultural pests.

Trichogramma releases have been used against pests on a wide variety of agricultural crops including industrial crops (beet, cotton, soybean, and sugarcane), cereals (corn, rice, and sorghum), vegetables (cabbage, pepper, and tomato), and tree crops (apple, citrus, grape, and olive) [26, 27, 35, 36]. During the past five decades, *Trichogramma* spp. have been evaluated as biological control agents for lepidopteran pest suppression in cotton [20, 37–40].

Augmentative releases of lacewings are released into commercial crops; they are released as first instar larvae at a rate of 1,000/ha, when released into sites with aphid infestations. Growers releasing lacewings early in areas without the nearby use of broad-spectrum organophosphate insecticides gained good control of aphids [41, 42]. However, the results are achieved by a combination of what is released, and the higher level of naturally occurring natural enemies in different sites. Smith [35] suggested that greater highlighting should be placed on the combination of more than one of bio-control agents, i.e., *Trichogramma* with other control options. Trials have shown that this combination can provide greater control of stem borers in corn in the USA [43], India [44], and China [45]. In Egypt, a biological control program of *Helicoverpa armigera* is the combined use of parasitoids and predators. The combination between parasitism of *Trichogramma* species and predation of *Chrysoperla carnea* on *H. armigera* was investigated under greenhouse [46]. This management type deserves greater attention as a practicable tactic in IPMs.

There were many examples for the successful use of the predatory phytoseiids against several pests. *Tetranychus urticae* is one of the most important pest infesting many fruit trees, field crops, vegetables and greenhouse crops [47] causes a reduction in the crop yields [48]. One of the most successful bio-control agents is *P. persimilis* which is used in controlling *T. urticae*. It is widely used commercially in the control of *T. urticae*. Other phytoseiid species have also been used to control *T. urticae*. For example, *N. californicus* has used successfully in the biological control of *T. urticae* [49]. Moreover, *N. californicus* has been reported to be effective in control of the broad mite, *Polyphagotarsonemus latus*, on pepper [50] as well as other tarsonemid mite pest *Phytonemus pallidus* on strawberry [51, 52].

Field application of EPNs does not require specialized application equipment since they are well matched with regular agrochemical tools, i.e., sprayers and irrigation systems. Each nematode species has a unique array of characteristics, including different environmental tolerances, dispersal tendencies, and foraging behaviors [24].

3 Pillars of Biological Control Industry

3.1 Abundance of Natural Enemies

Table 1 shows an assortment of survey attempts of some natural enemies in Egypt, including egg parasitoids, larval parasitoids, pupal parasitoids, aphid parasitoids, whitefly parasitoids, insect-scale parasitoids, insect predators, predatory mites, and entomopathogenic nematodes.

3.1.1 Parasitoids and Predators

Egg Parasitoids

Egypt cultivates about 105,000 ha of sugar cane yearly as a main crop of the sugar industry. The lesser sugar cane borer *Chilo agamemnon* is the most destructive pest of sugarcane in Egypt. Natural parasitism by the egg parasitoids *Trichogramma evanescens* on *C. agamemnon* egg masses reached up to 80% [85–87]. Unfortunately, this high rate of natural parasitism occurs at the end of the season and shortly before cropping. This pest attacks the crop in May, 1 month earlier than the parasitized activity [88].

Around the world today, *Trichogramma* species are the most broadly used as an insect natural enemy [26], partly because they are easy to mass production and they attack various important insect pests. The diversity of locally occurring egg parasitoid species had been surveyed and identified [56]. In Egypt, Fayad et al. [53] surveyed the natural enemies associated with the three corn borers, *Sesamia cretica*, *Chilo agamemnon*, and *Ostrinia nubilalis* in corn fields in Egypt. They recorded the egg parasitoids *Trichogramma evanescens* and *Platytelenomus hylas*, the larval parasitoids *Apanteles ruficrus*, *Bracon hebetor*, *Tachina larvarum*, and *Microplitis* sp. and the pupal parasitoids, *Conomorium eremita*, *Callitiola* sp. and *Rhoptrmeris* sp. Ragab et al. [54] surveyed the egg parasitoids associated with *Ostrinia nubilalis* and *Chilo Agamemnon;* they confirmed that *Trichogramma evanescens* was dominant in maize fields. Ragab et al. [55] investigated sorghum and maize fields to assess the egg parasitoids accompanying *S. cretica*, they found that *Platytelenomus hylas* has shown good efficacy in early of the season when *S. cretica* is dispersed.

Several *Trichogramma* species associated with eggs of the olive moth (*Prays oleae*) and the jasmine moth (*Palpita unionalis*) in olive groves in western desert in

Table 1 Abundance of natural enemies in Egypt

Crop	Natural enemy	Pest	Reference
1. Egg parasitoids			
Maize	*Platytelenomus hylas*	*Sesamia cretica*	Fayad et al. [53]
	Trichogramma evanescens	*Ostrinia nubilalis*, *Chilo agamemnon*	
Maize	*T. evanescens*	*Ostrinia nubilalis*, *Chilo agamemnon*	Ragab et al. [54]
Maize	*Platytelenomus hylas*	*Sesamia cretica*	Ragab et al. [55]
Olive	*T. bourarachae*, *T. cordubensis*, *T. euproctidis*, *T. evanescens*, *T. oleae*, *T. nerudai*	*Prays oleae*, *Palpita unionalis*	Hegazi et al. [40, 56]
Olive fields	*T. evanescens*	*Prays oleae*	Agamy [39]
Tomatoes	*Trichogramma*-29 strains	*Tuta absoluta*	El-Arnaouty et al. [16]
2. Larval parasitoids			
Maize	*Apanteles ruficrus*, *Bracon hebetor*, *Tachina larvarum*, *Microplitis* sp.	*Sesamia cretica*, *Ostrinia nubilalis*, *Chilo agamemnon*	Fayad et al. [53]
Guava or citrus fruits	*Aganaspis daci*	*Bactrocera zonata*, *Ceratitis capitata*	El-Heneidy et al. [19]
Tomatoes, Potatoes	*Bracon hebetor*, *Apanteles* spp.	*Phthorimaea operculella*, *Spodoptera littoralis*, *Agrotis ipsilon*	ELbehery [57]
3. Pupal parasitoids			
Maize	*Conomorium eremite*	*Sesamia cretica*	Fayad et al. [53]
	Callitiola sp., *Rhoptrmeris* sp.	*Ostrinia nubilalis*, *Chilo agamemnon*	
Maize	*Pediobius furvus*	*Sesamia cretica*	El-Wakeil et al. [58]
Cabbage	*Brachymeria femorata*	*Piers rapae*	Kamal [59]
4. Aphid parasitoids			
Wheat	*Aphidius matricariae*, *A. colemani*, *Diaeretiella rapae*, *Praon necans*, *Ephedrus persicae Trioxys* sp.	*Rhopalosiphum padi*, *R. maidis*, *Schizaphis graminum*, *Sitobion avenae*	El-Heneidy and Abdel-Samad [60], Sobhy et al. [61]
Wheat	*Aphidius matricariae*, *A. uzbekistanicus*, *Praon gallicum*	*Sitobion avenae*	Ibrahim and Afifi [62]
5. Whitefly parasitoids			
Tomato, Potato	*Encarsia Sophia*, *Eretmocerus mundus*, *E. siphonini*	*Bemisia tabaci*	Abd-Rabou and Abou-Setta [63], Abd-Rabou [64], Simmons and Abd-Rabou [65]

(continued)

Table 1 (continued)

Crop	Natural enemy	Pest	Reference
6. Scale insect parasitoids			
Mulberry trees	*Anagyrus kamali*, *Metaphycus* sp., *Allotropa mecrida*, *Scutellista caerulea*, *Chartocerus* sp.	*Ceroplastes rusci*, *Saissetia oleae*, *Icerya aegyptiaca*, *I. purchase*, *I. seychellarum*	Hendawy et al. [66]
7. Insect predators			
Maize	*Mantis religiosa*, *Labidura riparia*, *Orius albidipennis*, *O. laevigatus*, *C. carnea*, *C. undecimpunctata*, *Scymnus interruptus*, *Paederus alferii*	*Sesamia cretica*, *Chilo Agamemnon*, *Ostrinia nubilalis*	Fayad et al. [53], Ragab et al. [67, 68]
Wheat	*C. undecimpunctata*, *Scymnus* sp., *Paederus alferii*, *Orius* spp., *C. carnea*	*Rhopalosiphum padi*, *R. maidis*, *Schizaphis graminum*, *Sitobion avenae*	El-Heneidy and Abdel-Samad [60]
Cotton fields	*C. undecimpunctata*, *Scymnus* sp. *Paederus alferii*, *Orius albidipennis*, *O. laevigatus*, *C. carnea*, true spider	*Pectinophora gossypiella*	El-Heneidy et al. [69], Abou-Elhagag et al. [70]
Mulberry trees	*Orius* spp., *Coranus* sp., *Coccinella*, *undecimpunctata*, *Cydonia* sp., *Mantis religiosa*	*Brevipalpus* sp., *Panonychus ulmi*, *Icerya aegyptiaca*, *I. purchase*, *I. seychellarum*, *Ceroplastes rusci*, *Saissetia oleae*	Hendawy et al. [66]
Pigeonpea (*Cajanus cajan*)	*Coccinella septempunctata*, *Andrallus spinidens*, *Rhynocoris fuscipes*, *Camponotus* sp., *Mantis religiosa*	*Aphis fabae*, *Oxyrachis tarandus*, *Melanoplus bivittatus*, *S. indica*	Sayed [71]
Tomatoes	*Nesidiocoris tenuis*	*T. absoluta*	El-Arnaouty and Kortam [72]
8. Predatory mites			
Faba bean	*Typhlodrompis swirskii*	*T. urticae*	Romeih et al. [73]
Mango trees	*Amblyseius swirskii*, *A. yousefi*, *A. enab*, *A. cucumeris*, *T. swirskii*, *Agistemus exsertus*	*Oligonychus mangiferus*, *Brevipalpus obovatus*	Mohamed and Nabil [74]
Sweet pepper field	*P. macropilis*	*T. urticae*	Heikal and Ebrahim [75]
9. Entomopathogenic nematodes			
Field crops	*Heterorhabditids* spp.	Soil insect hosts	Shamseldeen and Abd-Elgawad [76], Abd-Elgawad and Nguyen [77]

(continued)

Table 1 (continued)

Crop	Natural enemy	Pest	Reference
Mango	*Heterorhabditis egyptii*	Soil insect hosts	Abd-Elgawad and Ameen [78]
Citrus	*Heterorhabditis indica*	Soil insect hosts	Abdel-Zaher and Abd-Elgawad [79], Abouelhag and El-Sadawy [80]
Hibiscus	*Heterorhabditis taysearae*, *Steinernema abbasi*, *Steinernema carpocapsae*	Soil insect hosts	Shamseldeen et al. [81, 82], Abu-Shady et al. [83]
	Steinernema Kushidai	Soil insect hosts	Atwa [84]

Egypt were surveyed, where *T. bourarachae*, *T. cordubensis*, *T. pretiosum*, and *T. cacociae* were recorded [39, 56]. In tomatoes, El-Arnaouty et al. [16] surveyed the natural enemy's associated *Tuta absoluta*, they mentioned that *Trichogramma* species were the dominant parasitoid.

Larval Parasitoids

Larval parasitoids come in the second important level after egg parasitoids. The following larval parasitoids *Apanteles ruficrus*, *Bracon hebetor*, *Tachina larvarum*, and *Microplitis* sp. were recorded on corn borers *S. cretica*, *C. agamemnon* and *O. nubilalis* in maize fields [53]. El-Heneidy and Sekamatte [89] surveyed the larval parasitoids of the cotton bollworms and recorded 21 parasitoid species belonging seven families. Of the 21 species, 10, 7, and 4 were found on *Helicoverpa armigera*, *Earias insulana*, and *Pectinophora gossypiella*, respectively. The larval parasitoid *Aganaspis daci* was retrieved from naturally infested *Bactrocera zonata* or *Ceratitis capitata* in guava or citrus orchards in Giza, Egypt [19]. Elbehery [57] found two larval parasitoids *Bracon* spp. and *Apanteles* spp. on the potato tuber moth *Phthorimaea operculella*, the cotton leafworm *Spodoptera littoralis*, and the black cutworm *Agrotis ipsilon*.

Pupal Parasitoids

In 1937 the most important pupal parasitoid *Brachymeria femorata* on the pupae of the cabbage worm *P. rapae* was recorded for the first time and described by Kamal [59]. Fayad et al. [53] surveyed this pupal parasitoid; *Conomorium eremite* against *S. cretica*; and other two wasp species *Callitiola* sp. and *Rhoptrmeris* sp. against *C. agamemnon* and *O. nubilalis* in maize fields. El-Wakeil et al. [58] surveyed and identified a pupal parasitoid (gregarious endo-parasitoid) *Pediobius furvus* (Eulophidae) of *Sesamia cretica* pupae in El-Beheira Governorate, Egypt. The parasitism percent were 8.4 and 15.4 in August and September, respectively. The parasitoids emerged from one pupa ranged from 28 to 222 wasps.

Aphid Parasitoids

There are several aphid parasitoids prevails on wheat aphids (*Rhopalosiphum maidis*, *Rhopalosiphum padi*, and *Sitobion avenae*) in Egypt. Ibrahim and Afifi [62] stated that the highest aphid counts on wheat cultivars at the end of March. *Aphidius matricariae*, *A. uzbekistanicus*, and *Praon gallicum* were the primary parasitoids of *Sitobion avenae*. El-Heneidy and Abdel-Samad [60] surveyed parasitoid species in the experimental wheat fields associated cereal aphid species which are mostly specific on a single or certain group of insect hosts: *Aphidius matricariae*, *A. colemani*, *Diaeretiella rapae*, *Praon necans*, *Ephedrus persicae*, and *Trioxys* sp. Sobhy et al. [61] surveyed the seasonal occurrence of aphid parasitoid species, associated with aphid on wheat plants. The results revealed the presence of these parasitoid species: *A. colemani*, *A. matricariae*, *Diaeretiella rapae*, *Praon necans*, *Ephedrus persicae*, *Aphidius* spp., and *Aphelinus* spp. Parasitism percent of *A. colemani* reached 21.7%.

Whitefly Parasitoids

The whitefly *Bemisia tabaci* is very important insect pest infesting most of vegetables and field crops in Egypt. The whiteflies parasitoids *Encarsia Sophia*, *Eretmocerus mundus E. siphonini* were surveyed for several years in Egypt [63–65]. These parasitoids can't control the whitefly population by themselves in Egypt. Therefore insecticides are still used to control this pest.

Scale Insect Parasitoids

Hendawy et al. [66] recorded the following parasitoids: *Encarsia citrina*, *Anagyrus kamali*, *Metaphycus* sp., *Allotropa mecrida*, *Scutellista caerulea*, and *Chartocerus* sp. during their studies on Mulberry trees infesting with scale insects.

Inset Predators

Insect predators belong to several orders (Heteroptera, Neuroptera, Diptera, Hymenoptera, and Coleoptera) and found in most of the environments throughout the world. Larvae and/or adults are the voracious predators of exposed eggs, small larvae of beetle and lepidopterous pests. It also feeds on slow-moving, soft-bodied arthropods such as aphids, jassids, thrips, whitefly, scales, mealy bugs, and mites.

In Egypt, *Mantis religiosa*, *Labidura riparia*, *Orius albidipennis*, *O. laevigatus*, *C. carnea*, *C. undecimpunctata*, *Scymnus interruptus*, and *Paederus alferii* associating with corn borers *S. cretica*, *C. agamemnon* and *O. nubilalis* in maize fields were recorded [53, 67, 68]. El-Heneidy et al. [70] surveyed the population of predators continually in clover then in cotton fields, who mentioned that the predators started to increase in the clover fields during March–May until it reached their peaks of abundance during late April and May. In June, the predators migrate to the cotton fields and achieve the maximum abundance in the latter fields during June and July. In cotton fields, El-Heneidy et al. [69] and Abou-Elhagag [90] surveyed some predators in Egypt; they recorded *Coccinella undecimpunctata*, *Scymnus* sp. *Paederus alferii*, *Orius* spp., *Chrysoperla carnea* and true spider. The considered predators reached their peaks during July and Early of August. *Orius* species was the dominant predator followed by spider. El-Heneidy et al. [91] counted visually the predatory species accompanying cotton pests in Uganda. They recorded immature and adults stages of several predators: coccinellids, anthocoris, staphylinidae, labiduridae, syrphidae, ants, and true spiders. El-Heneidy et al. [92] found that predators associated cotton insect pests were more dominant in early plantation than those in the late one, as well as in the mid of season than the end of the season.

The aphidophagous predatory species such as *C. undecimpunctata*, *Scymnus interruptus*, *Paederus alferii*, *Orius* spp., *Chrysoperla carnea* and true spider were recorded preying the cereal aphid species (*Rhopalosiphum padi*, *R. maidis*, *Schizaphis graminum*) in wheat fields [60]. A polyphagous predator widely distributed in the Mediterranean region, *Nesidiocoris tenuis* was recorded for the first time in Egypt associated with *T. absoluta* in aubergine and tomato plantations in Giza, Qalyubia, and Faiyum Governorates [72]. Sayed [71] recorded *C. septempunctata*, *Andrallus spinidens*, *Rhynocoris fuscipes*, *Camponotus* sp., and *Mantis religiosa* on Pigeonpea plants and mentioned that these predators played an important role in reduction insect pest population.

3.1.2 Natural Abundance of the Predatory Mites

Tetranychus urticae is a major pest on strawberry, and *N. californicus* is one of the most important phytoseiid predators feeding on that mite pest. The results of Greco et al. [93] suggested that *N. californicus* is a promising natural enemy for controlling *T. urticae* on strawberry. Domingos et al. [94] identified the mite fauna associated with grapevine in Brazil to evaluate the fluctuation of the populations of the phytophagous mites and their predators. *T. urticae* and *Oligonychus mangiferus* comprised 74% of phytophagous mites. *Euseius citrifolius* and *Neoseiulus idaeus* comprised more than 80% of Phytoseiid mites.

The seasonal abundance of *T. urticae* and the naturally occurring predatory arthropods were investigated on castor bean, Egypt [95]. Their results showed that *Stethorus gilvifrons* and *Scolothrips longicornis* were the predominated predacious insects of *T. urticae*. The abundance of *T. urticae* and its predator *S. gilvifrons* were the lowest in summer reaching its peak in spring. However, the mean abundance of *S. longicornis* was the highest in summer followed by spring, winter, and autumn. Romeih et al. [73] investigated the population density of *T. urticae* in Beheira Governorate, Egypt, during 2010–2012 on faba bean, and mentioned that the infestation of *T. urticae* reached their peaks during March. The predatory mite *Typhlodrompis swirskii* was firstly recorded at the beginning of January for the two seasons.

The predatory mite *Phytoseiulus macropilis* in sweet pepper field and spider mite, *T. urticae* were surveyed weekly by [75]. A predatory mite could appear naturally in the absence of harmful pesticides and could play a good role as a biological control agent. Mohamed and Nabil [74] investigated the mango orchards to find the predators associated with mite pests and found that *Amblyseius yousefi*, *A. enab*, *A. cucumeris*, *A. cydnodactylon*, *T. swirskii*, and *Agistemus exsertus* predatory mites were present in high numbers.

3.1.3 Natural Abundance of Entomopathogenic Nematodes

Surveys of entomopathogenic nematodes (EPNs) are useful for discovery of new species and strains, greater understanding of the nematode ecology and for expanded utilization of these nematodes in the biological control of insect pests [96, 97]. There are about 70 species of *Steinernema* and 25 species of *Heterorhabditis* have been described worldwide [98–100]. Use of *Galleria*-bait technique is common for isolation of entomopathogenic nematodes [101–107]. In this technique, larvae of the greater wax moth, *Galleria mellonella* is used for extraction of entomopathogenic nematodes from the soil. This insect is also used for laboratory evaluation of quality traits (including virulence) of entomopathogenic nematodes and for their in vivo mass production [97]. Surveys of EPNs have been conducted in many parts of the world [102, 108–112]. Hominick [113] reported that searching for entomopathogenic nematodes often yield numerous isolates of steinernematids and/or heterorhabditids; he found that between 2 and 46% of the collected samples were positive.

Entomopathogenic nematode research started in Egypt in the 1970s by late Dr. Tayseer El-Kifl when she worked on the bio-control of the cotton leaf worm *Spodoptera littoralis* with *Neoaplectana* (*Steinernema*) *carpocapsae* [114–116]. Native strains of EPNs were isolated for the first time in Egypt [117].

Identical surveys of EPNs in Egypt still in progress as Abd-Elgawad stated [118]. However, attempts of isolation of new EPNs are continuous in everywhere in Egypt. These continuous attempts are mostly irregular either in time or site [76–83]. The study of Saleh et al. [18] was the first population in a specific region for an expanded period in Egypt. In this study, biweekly soil samples were collected from fruit orchards on the area around Cairo-Alexandria desert road during January–June 2014 and 2015. These orchards contained trees of citrus, pomegranate, figs, grapes, date palms, olives, mangoes, guava, pears, peaches, and apples. Both *Steinernema* and *Heterorhabditis* genera could be isolated. The rate of nematode natural existence was varied according to the nematode genus and sampling time. Out of 180 soil samples, entomopathogenic nematodes were isolated 30 times (28 *Heterorhabditis* and 2 *Steinernema*). *Steinernema* was found in January and March while *Heterorhabditis* was found along the whole season with higher abundance in April–June. No clear relationship could be detected between the nematode abundance and the fruit type. Four isolates were selected for testing their virulence against the wax moth larvae *G. mellonella*. All tested isolates were virulent to the larvae with differences among them. Most of the previous attempts for isolation of entomopathogenic nematodes were through irregular field visits to different regions of Egypt, and most of the Egyptian nematode isolates belonged to *Heterorhabditis* spp. [81, 117]. However, *Steinernema carpocapsae* was identified for the first time in Egypt in 1996 [82] and *Steinernema kushidai* [84].

3.2 Mass Production of Some Natural Enemies

Table 2 shows a collection of mass production attempts of some natural enemies in Egypt, including egg parasitoids, larval parasitoids, insect predators, predatory mites, and entomopathogenic nematodes.

Table 2 Mass production of some natural enemies

Natural enemy	Host	Crop	Strategy and technique	References
Egg parasitoids *Trichogramma* species	*Sitotroga cerealella*, *Ephestia kuehniella*	Olive Maize Cotton Grape Sugarcane	*Sitotroga* eggs on wheat kernel or *Ephestia* eggs on wheat flour in big tries, hatching, full larvae, pupation, adults, finally getting the fresh egg to mass rearing *Trichogramma*	Abdel-Hafez et al. [119], El-Wakeil [31], Hegazi et al. [40]
Larval parasitoids *Bracon hebetor*, *B. brevicornis*	*O. nubilalis*, *S. cretica*, *A. ipsilon*	Maize Cotton	Mean numbers of parasitoid's progeny per host larva were 9.6 (*O. nubilalis*), 9.3 (*S. cretica*) 7.3 (on *A. ipsilon*)	Kares et al. [120], Abd El-Wahab et al. [121]
Insect predators *Chrysoperla carnea*	Aphids, new larvae, artificial diets	Wheat Cotton Maize	The cannibalistic larvae were kept individually in hard gelatin capsules to avoid the use of anesthesia or vacuum sucker in handling of the insects	Ashfaq et al. [122, 123], Sattar and Abro [124]
Predatory mites *Phytoseiulus persimilis*, *P. macropilis*	*T. urticae*	Bean Strawberry	Mass produced and released of the predatory mite to control *T. urticae* in the fields	Morales-Ramos and Rojas [125], Heikal et al. [52]
EPNs	*G. mellonella*	Maize Fruit trees	In vivo and in vitro	Metwally [126], Ehlers [127]

3.2.1 Mass Production of Parasitoids and Predators

Egg Parasitoids (*Trichogramma*)

Trichogramma was mass reared on different factitious hosts, including advantages and disadvantages of these systems as mentioned by El-Wakeil [31]. The focus on the hosts arises from the fact that only minor differences exist in the last step of *Trichogramma* production thus the host rearing is usually the most important step that decides on cost efficacy and viability of *Trichogramma* production.

The eggs of *S. cerealella* are mostly used as a laboratory host for *Trichogramma* in Egypt, Europe as well many countries over the world. It is the first alternative host on which *T. evanescens* was successively reared on. Based on the mass rearing techniques for *S. cerealella* reported by Konig et al. [128], we developed a method with adapted procedures and equipment for mass rearing *Trichogramma*. *Trichogramma* has been mass-reared since early of the 1980s with peak production of million wasps/day. The cost of production of *Trichogramma* species was reduced by 1/3 through improvement of *S. cerealella* egg collecting facilities [39, 119, 129].

Mass rearing of factitious hosts for *Trichogramma* production is labor intensive and costly, besides being affected by abiotic and biotic factors. Studies on the rearing of *Trichogramma* in vitro on artificial host eggs began in the middle of 1970s in China [130]. Further research has shown that efficacies are similar to the same species reared from the factitious eggs. Oviposition stimulants that improved egg production by *Trichogramma* were selected [131]. Mechanized production of *Trichogramma* with artificial host eggs has been successful. A prototype for producing artificial host eggs was manufactured which automatically completes all five processes, including setting up synthetic membrane, forming the "egg-shells," injecting the artificial media into the shells, sealing the double-layered membrane, and separating into egg cards [132, 133]. Parasitism rates are similar to those achieved by wasps reared on normal eggs [134]. The parasitoids from in vitro rearing have been used for control of Asian corn borer and cotton bollworm over 150,000 ha in the 1990s [130]. A releasing container for Trichogramma reared on artificial host eggs was also designed, and the emergence rate was over 90% [135].

Mass Production of Larval Parasitoids (*Bracon* Species)

The full-grown wax moth larvae *Galleria mellonella* were used for rearing the Braconid wasps. These larvae were transferred into a jar (20 larvae/jar) with a folded corrugated paper sheet, where full-fed larvae took a position on the corrugated paper sheet for pupation (Fig. 3). Pairs of female and male *Bracon* spp. adults – 1–2 days old were released in the jar covered with muslin cloth then fitted with rubber lids for parasitism and egg lying. Drops of honey were added on jar wall as a food source which made vital effects on the efficiency of parasitoid wasps [121]. The parasitoids were transferred daily, to a new jar prepared with a

Fig. 3 The full-grown larvae *G. mellonella* with adults *Bracon hebetor*

corrugated paper sheet with fresh host larvae until the death. The corrugated paper sheet with parasitized larvae was kept until pupation and adult emergence, which will be prepared to mass release in the target fields. Kares et al. [120] reared the ecto-larval parasitoid species, *Bracon brevicornis* on three different hosts: *Ostrinia nubilalis*, *Sesamia cretica* and *Agrotis ipsilon*. Mean numbers of parasitoid's progeny per host larva were 9.6 (on *O. nubilalis*), 9.3 (on *S. cretica*), and 7.3 (on *A. ipsilon*).

Insect Predators

Sattar and Abro [124] mass reared *Chrysoperla carnea* adults for Integrated Pest Management Programs of some target insect pests. Rearing techniques for *C. carnea* have been improved to have its mass rearing in the laboratory and to make releases in fields. In this technique, the cannibalistic larvae were kept individually in hard gelatin capsules (500 mg) to avoid the use of anesthesia or vacuum sucker in the handling of the insects, as used in old techniques. After 10 days of larval development, the formed pupae were collected, and then these pupae were placed in cages for adult emergence and egg deposition. Harvested eggs were used for field application [122, 123, 136].

3.2.2 Mass Production of Predatory Mites

Phytoseiulus persimilis is one of the successful bio-control agents of spider mites on vegetables in glasshouses and field crops [21, 137, 138]. Since its introduction approximately 40 years ago, phytoseiids have gained recognition for their importance as natural enemies of thrips, whiteflies, and spider mites [139]. Zhang [33] reported that at least 20 species of phytoseiids were available at a commercial scale. *P. persimilis* was the most phytoseiid mite that has been widely mass-produced and sold commercially [140]. In Egypt, commercial mass production of predators in Egypt is still in progress. Attempts of predator production are limited to field experimentation, rather than commercial purposes. Heikal et al. [52] produced and released of the predatory mites *P. macropilis* to control *T. urticae* in strawberry fields.

Manual Methods

Mass production of phytoseiid mites such as *P. persimilis* depends on bean plants that grow in the greenhouse for spider mite production and later the introduction of the predatory mite was done. Infested leaves from the pure culture are used to infest bean plants in the greenhouses to provide a continuous source of the prey. Predators are later introduced to plants heavily infested with spider mites. The bean plants are harvested when it arrived at the maximum density of the predator [141].

In Egypt, the biological fitness of the phytoseiid mites, *N. californicus*, *T. swirskii* and *Euseius scutalis* was studied by Romeih et al. [142] when they offered *Corcyra cephalonica* and/or *Ephestia kuehniella* eggs as food. The first species, *N. californicus*, failed to feed on *C. cephalonica* eggs at the two tested temperatures (25 and 30°C) and could not complete its life cycle. Concerning the three other species, all of them displayed a better fitness at 30°C than at 25°C, where *T. swirskii* and *E. scutalis* responded positively for rearing on both eggs of *C. cephalonica* and *E. kuehniella*. However, *T. swirskii* showed a better response to this diet than the prior species.

Rearing of the Phytoseiid Mites and Cage Design

The rearing system existing here was described by Morales-Ramos and Rojas [125]. This system is based on the main principles of the stacked cage of Fournier et al. [143], but an exclusive modular structure of matching cage units was designed. Stackable modular units were built from storage containers (a), 250 mL plastic laboratory funnels (b), 120 mL specimen containers, and (c) 50 mL plastic centrifuge tubes (d) (Fig. 4).

The infested bean leaves with a high density of *T. urticae* were put in every cage unit stacked vertically to let mites to walk up. A cage series can be initiated by introducing a small number of adult predatory mites (10–100) in the cage unit filled recently with infested leaves. After the reduction of the prey mites, a new unit is connected to the old unit top by removing the connection cup cover to let the predators to go to the new unit.

3.2.3 Mass Production of Entomopathogenic Nematodes

Entomopathogenic nematodes can be produced through either in vivo or in vitro techniques. For the laboratory use and small-scale field testing, in vivo production of EPNs is the appropriate method where larvae of the greater wax *Galleria mellonella* are usually used [144]. For commercial use of EPNs at a larger scale

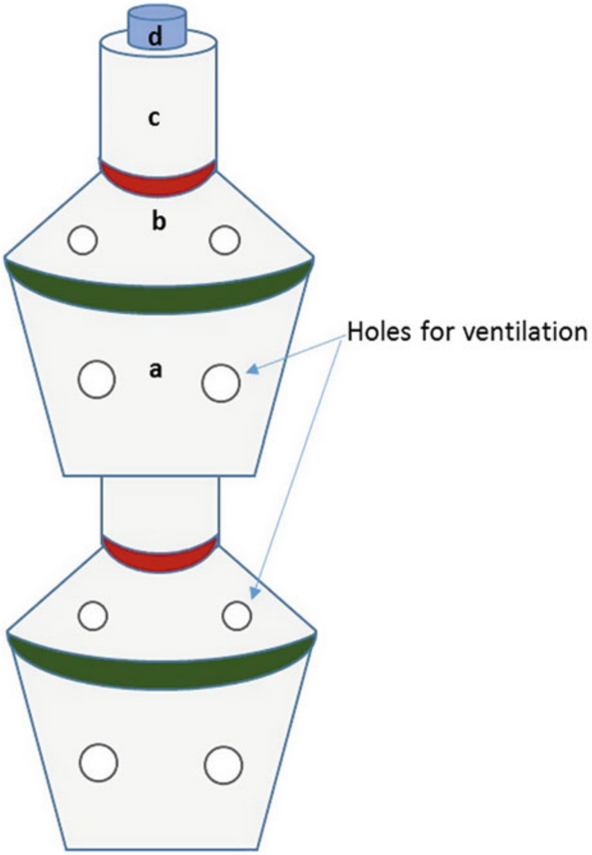

Fig. 4 Design of rearing cage of predatory mite, consisting of two units

for international markets, in vitro production is currently used. EPNs can be grown on Petri dishes using different agar media [145, 146]. A major improvement in mass production was achieved by Bedding [147] when he produced *Steinernema* spp. on a three-dimensional medium in flasks, using polyether-polyurethane sponge as a medium carrier. Autoclavable plastic bags can be used to scale up this method [148]. Bedding et al. [149] developed a culture vessel comprising a tray with side walls and overlapping lids that allowed gas exchange through a layer of polyether-polyurethane foam. These trays are particularly well suited for developing countries as forced aeration is not necessary, making this system independent from cuts in the power supply. Nematodes can be extracted from solid media with centrifugal sifters, or by washing nematodes out of the sponge in simple washing machines and then separating the IJ by sedimentation or migration. The process of industrialization of in vitro solid-state production of EPNs includes the culture of symbiotic bacteria, production of EPN, harvest, quality control, and storage [150–152].

In Egypt Metwally [126] studied the suitability of native and imported EPNs to in vitro production using the agar plates firstly then the Bedding flasks techniques.

The Egyptian nematodes differed significantly in their production ability on agar plates according to the nematode species and used the medium. *S. carpocapsae* BA2 achieved its highest production on medium composed of "starch 6 g, glucose 5 g, yeast extract 7.5 g, agar 8 g, corn oil 5 ml and 500 ml water" (about 1 million nematodes/dish of 9 cm in diameter). It was the first tray to propagate an Egyptian nematode on an artificial medium. *S. riobrave*, the worldwide well-known EPN, propagated the best also on the same medium giving 1.16 million nematodes/dish. The Egyptian *H. bacteriophora* BA1 propagated successfully on the same media however it failed to propagate on other media. The worldwide *H. marelatus* successfully propagated on most tried artificial media. Virulence of EPNs produced from in vivo and in vitro (agar plates) against larvae of *G. mellonella* was statistically the same. Propagation ability in *G. mellonella* larvae of EPNs produced from in vivo or in vitro (agar plates) was statistically comparable. Neither *S. carpocapsae* BA2 nor *H. bacteriophora* BA1 could continue growth in studied media in Bedding-flasks. However *S. riobrave*, *H. marelatus*, *S. scapterisci* and the local isolate *Steinernema* sp. SA succeeded in propagation using the Bedding-flask technique. Numbers of produced nematodes differed significantly according to the nematode and the used growth medium. *S. riobrave* achieved the highest offspring production on both used media reaching 45.54×10^6 IJs/500cc flask. The subculture of EPNs in Bedding-flasks was successful when two cubes (containing approximately 4 g growth medium) of sponge were transferred to a new flask.

3.3 Field Application of Natural Enemies

Natural enemies are released in the fields in different stages according to the kind of the natural enemies, for example the egg parasitoid *Trichogramma* is released as parasitized host eggs. The larval parasitoids are usually released as adult wasps. The aphid parasitoids are applied as host mummies, while the white fly parasitoids are released in the pupal stage. The lacewing *Chrysoperla carnea* is released in the egg and larval stages. The coccinellid predators may be applied as larvae or adults. The anthocoris predatory bug is released in the nymph or adult stages. The predatory mites are released in the adult stage. Table 3 shows the mass field application trials of some natural enemies in Egypt, including egg parasitoids, larval parasitoids, aphid parasitoids, whitefly parasitoids, insect-scale parasitoids, insect predators, predatory mites, and entomopathogenic nematodes.

3.3.1 Field Application of Parasitoids and Predators

Egg Parasitoids

Trichogramma evanescens is extensively used in inundative releases against some lepidopterous pests in Egypt as well as in Europe and over the world. Both,

Table 3 Examples of field application of natural enemies in different crops

Crop	Natural enemy	Pest	Findings	Reference
1. Egg parasitoids				
Cotton	*Trichogramma evanescens*	*Pectinophora gossypiella*, *Earias insulana*, *Helicoverpa armigera*	Significant effects	El-Wakeil [153], Abdel-Hafez et al. [119], Saad et al. [154]
Maize Sorghum	*T. evanescens*	*S. cretica*, *O. nubilalis*, *C. agamemnon*	The parasitism % increased markedly and steadily as the season advances	Ragab et al. [54]
Sugarcane fields	*Trichogramma* spp.	*Chilo agamemnon*	86% parasitism rates 65% damage reduction	El-Heneidy et al. [88], Abbas [155]
Olives	*Trichogramma* spp.	*Prays oleae*, *Palpita unionalis*	Egg parasitism 91% Larval population reduction 83%	Herz and Hassan [156], Hegazi et al. [40, 157]
Grape orchards	*T. evanescens*	*Lobesia botrana*	97% parasitism 96.8% damage reduction	El-Wakeil et al. [36]
Tomatoes	*Trichogramma* (29 strains)	*Tuta absoluta*	Keeping the damage of *Tuta absoluta* under an acceptable threshold	Khidr et al. [158], El-Arnaouty et al. [16]
Tomatoes	*Trichogramma* spp.	*Helicoverpa armigera*	Infestation reduction reached to 72%	El-Heneidy et al. [159]
Cabbages	*T. buesi*	*Pieris rapae*	Significant reduction	Abbas [160]
2. Larval parasitoids				
Maize	*Bracon brevicornis*	O. *nubilalis*, *S. cretica*	Highly significant effect on corn borers	Zaki et al. [161]
Fruit orchards	*Aganaspis daci*	*Bactrocera zonata*	Significant reduction	El-Heneidy et al. [19]
Tomatoes, potatoes	*B. hebetor*, *Apanteles* spp.	*Phthorimaea operculella*, *S. littoralis*	Significant effects	Elbehery [57]
Cabbage field	*Diaeretiella rapae*, *Eretmocerus mundus*	*Brevicoryne brassicae* *B. tabaci*	Resulted in 32% parasitism	Zaki et al. [162]
3. Aphid parasitoids				
Wheat	*A. matricariae*, *A. colemani*, *D. rapae*, *P. necans*, *E. persicae*	*R. padi*, *R. maidis*, *S. graminum*, *S. avenae*	Significant effects	El-Heneidy [163]

(continued)

Table 3 (continued)

Crop	Natural enemy	Pest	Findings	Reference
Cabbage, Faba bean, Oleander	*Diaeretiella rapae*	*Brevicoryne brassicae*, *Aphis craccivora*	Up to 92% parasitism	Saleh [164]
4. Whitefly parasitoids				
Tomatoes	*Eretmocerus siphonini*, *Encarsia Sophia*, *E. mundus*	*Bemisia tabaci*	The parasitism rates reached 65% They are an effective bio-control agents of whiteflies in Egypt	Abd-Rabou and Abou-Setta [63], Abd-Rabou [64], Simmons and Abd-Rabou [65]
5. Scale insect parasitoids				
Citrus Guava Olive Mango	*Coccophagus scutellaris*	Soft scale insects	*C. scutellaris* showed a significant correlation with the buildup of scale insects population	Abd-Rabou [165–168]
6. Insect predators				
Cotton	*C. undecimpunctata*, *Scymnus* sp. *Paederus alferii*, *Orius* spp., *C. carnea*	*H. armigera*, *E. insulana* *P. gossypiella*	Significant effects	El-Heneidy et al. [69, 91, 92]
Faba bean	C. *carnea*, *C. undecimpunctata*	*Aphis gossypii fabae*	100% reduction in *Aphis gossypii*	Zaki et al. [162]
	Harmonia axyridis	*Aphis craccivora*	Significant reduction	El-Arnaouty et al. [169]
Green pepper	*Chrysoperla carnea*	*Myzus persicae*	Successful control of aphids	El-Arnaouty et al. [170]
Ornamental plant	*Cryptolaemus montrouzieri*	*Ferrisia virgata*	Reduction % reached to 99.99	Attia and El-Arnaouty [171]
Ornamental shrubs	*C. montrouzieri*	*Planococcus citri*	Reduction rates reached to 100%	Afifi et al. [172]
7. Predatory mites				
Faba bean	*N. californicus*, *T. swirskii*	*T. urticae*	The predators decreased the spider population density	Elmoghazy et al. [49]
Apple	*P. persimilis*	*T. urticae*	The predator caused high reduction in pest infestation up to 89%	Metwally et al. [173]
Sweet pepper	*P. macropilis*	*T. urticae*	The densities remained more less the economic levels	Heikal and Ebrahim [75]

(continued)

Table 3 (continued)

Crop	Natural enemy	Pest	Findings	Reference
8. Entomopathogenic nematodes				
Maize	*S. carpocapsae*, *H. bacteriophora*,	*Sesamia cretica*	67.8 larval mortality 97–100% larval mortality	Saleh et al. [174], El-Wakeil and Hussein [175]
	H. bacteriophora	*Ostrinia nubilalis* larvae	Significant reduction	Saleh and El-Kifl [176], Saleh [177]
Spring wheat	*H. bacteriophora*, *S. carpocapsae*, *S. feltiae*	*Oscinella frit*	*S. carpocapsae* was more efficacious than *S. feltiae* and *H. bacteriophora*	El-Wakeil and Volkmar [178]
Date palm	*Heterorhabditids* spp., *Steinernema* spp.	*Rhynchophorus ferrugineus*	60–98% pupal mortality 90% adult mortality	Saleh et al. [179]
Fruit trees	*S. carpocapsae*, *H. bacteriophora*	*Zeuzera pyrina*, *Synanthedon myopaeformis*	76% larval mortality	Abdel-Kaway et al. [180, 181], El-Shazly et al. [182]
Strawberry	*H. bacteriophora*, *S. glaseri*, *S. carpocapsae*	*Temnorhynchus baal*	96.8–99.1% larval mortality	Shamseldeen and Atwa [183]
Cauliflower	*H. bacteriophora*, *H. indica*	*Tropinota squalid*	83.3–94.7% adult mortality	Abdel-Razek and Abd-Elgawad [184]
Cabbage	*H. taysearae*, *S. carpocapsae*, *H. bacteriophora*	*Artogeia (Pieris) rapae*, *Hellula undalis*	96.3% larval mortality	Saleh [185]
Sugar beet	*S. carpocapsae*, *S. feltiae*, *H. bacteriophora*	*Cassida vittata*, *Pegomyia mixta*	Larval mortality 65% Pupal mortality 92% Adult mortality 57% Larval mortality 76% Larval mortality 81%	Saleh et al. [186, 187]
Chamomile	*H. bacteriophora*, *S. carpocapsae*	*Microplontus rugulosus*, *Olibrus aeneus*	EPNs had achieved a significant reduction in insect damage	Gaafar et al. [188]

(continued)

Table 3 (continued)

Crop	Natural enemy	Pest	Findings	Reference
Vegetables and field crops	*S. riobrave*, *Steinernema* spp., *Heterorhabditids* spp.	*Plant parasitic Nematodes Meloidogyne* spp.	Significant effects	Abd-Elgawad and Abul-Eid [189]
Tomato	*S. carpocapsae*, *H. bacteriophora*, Trapping fungi	Root-knot nematodes *Meloidogyne incognita*	Significant reduction	Noweer and El-Wakeil [190]

inoculative and inundative approaches have been evaluated and applied for biological control of maize, cotton, grape, sugarcane, etc. in Egypt. Inoculative releases aim to support naturally occurring populations of the biological control agent by releasing small agent numbers before the pest populations buildup.

Inundative releases of 150,000–300,000 wasps/ha at 45 release points/ha generated egg parasitism rates of 60–85% with an associated reduction in crop damage of 65–92% [191, 192]. Releases of 610,000 wasps/acre per week over a period of 5–9 weeks in Mexico reduced tomato fruit worm populations by 80–90% and fruit damage was often comparable to plots treated with conventional insecticides [193]. Similarly, for glasshouse tomatoes in Brazil, a release rate of 800,000 wasps/ha has reduced fruit damage by tomato borer to levels that are comparable to the use of conventional insecticides [29]. In Egypt, 11 two-weekly releases of 3 million female wasps/ha through the season proved to be very effective in suppressing two key lepidopteran pests of olive [157]. Other examples that provide good evidence of the success of inundative releases of *Trichogramma* are the use of *T. pretiosum* in tomato for control of *Helicoverpa zea* in Mexico and for control of *Tuta absoluta* in Brazil, and initial trials with indigenous *T. buesi* for control of cabbage worm in Egypt [160].

In olive orchards, Herz and Hassan [156] studied many of indigenous *Trichogramma* strains in olive groves in the Mediterranean region (*T. bourarachae*, *T. cacoeciae*, *T. cordubensis*, *T. euproctidis*, *T. nerudai*, *T. oleae* as well as commercially available strains (*T. brassicae*, *T. cacoeciae*, *T. evanescens*). They obtained that these indigenous *Trichogramma* strains attribute as biological control agents against lepidopterous olive pests like *Prays oleae* and *Palpita unionalis*. Hegazi et al. [157] evaluated the efficacy of released *Trichogramma* species in controlling *Prays oleae* and *Palpita unionalis* in olive groves in Egypt, and found that the released parasitoids accomplished higher egg parasitism (up to 91%). Larval densities of target pests were significantly reduced up to 83% on *Trichogramma* release trees in comparison to control trees. Hegazi et al. [40] selected four species of genus *Trichogramma* and compared aiming to select suitable candidates for control of lepidopteran olive pests. Three of them (*T. bourarachae*, *T. cordubensis*, *T. euproctidis*) had been collected from olive groves, whereas the commercially available strain used (*T. evanescens*) was originally isolated from sugarcane fields.

Among the cereal crops, successful attempts in Egypt with *T. evanescens* to control the lesser sugarcane *Chilo agamemnon* (Abbas et al. [194]; El-Heneidy et al. [88]; Abbas [155]). European corn borer, *Ostrinia nubilalis* and *C. agamemnon* have been managed by releasing *Trichogramma* wasps as reported by El-Wakeil and Hussein [175]. Similar studies have been conducted by releasing *Trichogramma* to control Asian corn borer, *O. furnacalis* in the Philippines [195]. Successful trials to control the grape moth *Lobesia botrana* in vineyards in Egypt have been studied by El-Wakeil et al. [36], who mentioned that parasitism rates reached 97% and the percentage of reduction in damage reached 96.8%. Hegazi et al. [196] reported that the combined effect of inundative releases of egg wasps, *T. evanescens*, with mating disruption technique was successful and could provide a model for control of lepidopterous pests of olive trees. Crop fields also had a great attention from Egyptian researchers, cotton bollworms have been managed using *Trichogramma* wasps [119, 153, 154].

Field application techniques for inundative releases of *Trichogramma* have been greatly improved since the 1980s. The release frequency has decreased from 3 to 2 releases for controlling some insect pests [88]. El-Heneidy et al. [197], Abdel Hafez et al. [119] mass released *Trichogramma evanescens* for controlling cotton bollworms in Egyptian cotton fields; these field applications reduced the bollworm infestation up to 56%. El-Heneidy et al. [159] evaluated different releases, timing and number of releases of *Trichogramma* wasps against *Helicoverpa armigera* in tomato fields. The results obtained showed that 40,000 parasitoids/Fed, four-time releases at interval of 10–15 days at the flowering stage gave the best result (infestation reduction reached to 72%). Field experiments were conducted by Mohamed et al. [198] to evaluate the efficacy of releasing *Trichogrammatoidea bactrae* at two growth stages (flowering and boll formation) and at different rates of releases (one to four releases) for suppressing the cotton bollworms, *Pectinophora gossypiella* and *Earias insulana* infestation and obtained a significant reduction up to 90 and 93% with *P. gossypiella* and *E. insulana*, respectively. They concluded that 4-releases of parasitoid at the flowering stage achieved the best results; reducing the pest infestation and gaining the high yield.

In tomatoes, El-Arnaouty et al. [16] mentioned in their study that efficiency of *Trichogramma euproctidis* and *T. achaeae* could keep the damage levels of *Tuta absoluta* under an acceptable threshold, when compared to the untreated control plants; therefore, the researchers recommended using *T. euproctidis* as a safe and effective strategy in IPM programs to manage *T. absoluta* in Egypt. Khidr et al. [158] applied *Trichogramma evanescens* to control *Tuta absoluta*. The obtained results revealed that the highly increase in the reduction was occurred in treated plots compared to control ones.

Large ecological and economic benefits have been achieved in areas where *Trichogramma* have been released continuously for many years. *Trichogramma* was released in large numbers for biological pest control in Egypt. Furthermore, other untargeted pests were affected by *Trichogramma* releases in these fields.

Larval Parasitoids

A pilot trial to mass release parasitoid *Aganaspis daci* against *Bactrocera zonata* under field conditions in Egypt was conducted by El-Heneidy et al. [19] and obtained a significant reduction of insect population. Zaki et al. [161] reported that the highly significant effect of kairomones was recorded by increasing parasitism rates by *Bracon brevicornis* on *S. cretica* and O. *nubilalis*. Zaki et al. [162] released *Diaeretiella rapae* to control *Brevicoryne brassicae*, and obtained 29% parasitism in cabbage field. Releasing *Eretmocerus mundus* for controlling *B. tabaci*, resulted in 32% parasitism in cabbage field.

Aphid Parasitoids

Aphid parasitoids *Aphidius matricariae*, *A. colemani*, *D. rapae*, *P. necans*, *E. persicae* *Trioxys* sp. had played a vital role in controlling cereal aphids [163]. On the other hand, Saleh [164] reported that the highest percentage of parasitism were 92.20, 83.20, and 79.30% for *Diaeretiella rapae* at 20 parasitoids/200 aphids (*Brevicoryne brassicae*, *Aphis craccivora*, and *A. nerii*) in semi-field test, respectively. A minimum of 61.80, 48.70, and 41.50% recorded at five parasitoids per cage on *Brevicoryne brassicae*, *Aphis craccivora*, and *A. nerii* infesting cabbage, respectively.

Whitefly Parasitoids

Eretmocerus siphonini is considered a bio-control agent for controlling two species of whiteflies in Egypt as confirmed by Abd-Rabou [64, 165] who found that the parasitism rates reached 65%. Simmons and Abd-Rabou [65] recorded *Encarsia Sophia* and *Eretmocerus mundus* that are useful for whitefly management in Egypt.

Scale Insect Parasitoids

Mass releasing of 953,000 individuals of *Coccophagus scutellaris* was applied by Abd-Rabou [166] for controlling the soft scale insects (Hemiptera: Coccidae) infesting the following economic crops in Egypt: *Ceroplastes rusci* on citrus in Beni Suef, *Ceroplastes floridensis* on citrus in Gharbia, *Coccus hesperidum* on guava in Giza, *Pulvinaria floccifera* on mango in Sharqia, *Pulvinaria psidii* on mango in Ismailia, *Saissetia coffeae* on olive in Mersa Matruh, and *Saissetia oleae* on olive in the Northern Coast. The population of *C. scutellaris* showed a significant correlation with the buildup of the population of the soft scale insects population in all of the release sites studied [167, 168].

Insect Predators

The well-known predators in cotton fields such as *C. undecimpunctata*, *Scymnus interruptus*, *Paederus alferii*, *Orius albidipennis*, *Orius laevigatus*, *C. carnea* were evaluated [69, 91, 92]. They confirmed that these predators played a significant role in reducing the cotton insect populations. Zaki et al. [162] applied two predators, C*hrysoperla carnea* and *Coccinella undecimpunctata* under greenhouse against *Aphis gossypii*, *A. fabae*. Double releases of *C. carnea* (1:5 predator: aphids) achieved 100% reduction in *A. gossypii* after 12 days. A single release of *C. undecimpunctata* (1:50 predator: aphids) resulted in 99.97% reduction in the same aphid. Three releases of *C. undecimpunctata* adults in a greenhouse cultivated with soybean decreased *A. fabae* population from 207 to 7.6 aphids/plant. El-Arnaouty and Sewify [199] conducted a pilot experiment of using eggs and larvae of *Chrysoperla carnea* against *Aphids gossypii* on cotton in Egypt. They mentioned that *C. carnea* achieved a significant reduction of *A. gossypii* population.

Releasing of *Harmonia axyridis* for biological control of *Aphis craccivora* was conducted on faba bean plants in open field. Results showed that *H. axyridis* was able to control aphids and gave a significant reduction in its population [169]. The aphid *Myzus persicae* was controlled by releasing eggs and second instar larvae of *Chrysoperla carnea* on green pepper plants [170]. Successful control of aphids was observed in the treated greenhouses while in the controlled greenhouse, there is a high aphid infestation.

The coccinellid predator *Cryptolaemus montrouzieri* was released by Attia and El-Arnaouty [171] to control the striped mealybug, *Ferrisia virgata* on the ornamental plant *Acalypha macrophylla* in *Egypt*. Adults of the predator were released once in October in the open field and they obtained that the percentage of reduction of *F. virgata* reached to 89.6 for crawlers, 75.01 for nymphs, and 67.62% for adults and increased in the 11th week after release to reach 99.99 for crawlers, 89.25 for nymphs, and 95.39% for adults. Afifi et al. [172] applied the *C. montrouzieri* to control the citrus mealybug, *Planococcus citri* on the croton ornamental shrubs, *Codiaeum variegatum*. One month after releasing, the reduction percentages of the egg masses, nymphs, and adults of *P. citri* reached to 41.5, 42.3, and 57.5%, respectively. Two months later, the corresponding rates were 80.6, 86.5, and 91.5%. Finally, after 3 months of releasing the predator, reduction rates reached to 100% for all stages of the pest https://www.ncbi.nlm.nih.gov/pubmed/20464943.

3.3.2 Field Application of Predatory Mites

The phytophagous mite pests can be controlled by a mixture of biological and chemical techniques that give less expensive and more permanent method of control than had the chemicals alone [200]. However, the determination of selective pesticides for using in IPM programs is essential to preserve the natural enemies and simultaneously decrease the contamination of the environment. A low toxicity of those pesticides to beneficial organisms is highly important [201].

The predatory phytoseiid mite *P. persimilis* was released at levels (10, 20, and 30 adults/apple seedling) in April and July. After 7 months from the 1st and 2nd release, the *T. urticae* infestation was reduced to 62, 81, and 89% [173]. The efficiency of two phytoseiid mites, *N. californicus* and *T. swirskii* was evaluated as bio-control agents for *T. urticae* on *Vicia faba* in faba field in Beheira Governorate during 2008 [49]. The predator *N. californicus* clearly decreased the population density of *T. urticae* compared with *T. swirskii*. The release of *N. californicus* and *T. swirskii* can be used usefully in the management strategy of *T. urticae*. Heikal and Ebrahim [75] released *P. macropilis* for controlling *T. urticae* on sweet pepper plants (60,000–100,000 predators/feddan). The densities of *T. urticae* remained fewer than the economic threshold levels. Heikal et al. [202] advised to release the predatory mite *P. macropilis* to control *T. urticae* on rose bushes early in the season.

Recently, the acaricidal activity of *Melissa officinalis* essential oil and its formulation (Melissacide) were studied against *T. urticae* and three predatory phytoseiid mites: *N. californicus*, *T. swirskii* and *N. barkeri* that can be used as successful tools to control *T. urticae* [203, 204]. However, Melissacide was found to have a slight negative effect on *N. californicus*, so that it can be used safely with *N. californicus* for controlling of *T. urticae* [22]. Knowledge of the oil-based pesticide selectivity to the beneficial predatory mites is vital to their efficacy use in IPM program in Egypt.

3.3.3 Field Application of Entomopathogenic Nematodes

Entomopathogenic nematodes (EPNs) are mass produced and don't require specialized application equipment since they are compatible with standard agrochemical equipment, including various sprayers and irrigation systems [205]. Efforts to control foliage-feeding pests with EPNs are recently successful in some cases. Each nematode species has a unique array of characteristics, including different environmental tolerances, dispersal tendencies, and foraging behaviors [206]. "Increased knowledge about the factors that influence EPN populations and the impacts they have in their communities will likely increase their efficacy as biological control agents" [177, 207, 208].

Not only inactive season but also in hibernating season, EPNs are effective and play a good role in IPM. Saleh and El-Kifl [176] found that *H. bacteriophora* can kill the hibernating larvae of corn borer, *Ostrinia nubilalis* inside their tunnels in stored corn stalks. Saleh et al. [174] sprayed corn plants infested with *Sesamia cretica* larvae with *H. taysearae* and *H. bacteriophora* and obtained 67.8 and 40.6% larval mortality within 1 week. El-Wakeil and Hussein [175] evaluated EPNs to control *Sesamia cretica* infesting corn hearts by spraying EPNs, resulted in a 97% and 100% mortality of insect larvae with *H. bacteriophora* and *S. carpocapsae*, respectively, 1 week post spraying. After 2 weeks there was a 100% mortality of *S. cretica* due to both EPN species.

In sugar beet crop, Saleh et al. [186] applied EPNs for controlling sugar beet beetle *Cassida vittata* naturally infested with larvae, pupae, and adults. Single spray of *S. carpocapsae* of 1,000 IJs/ml killed 65% of the larvae, 92% of the pupae, and 57.3% of the adults of *C. vittata* within a week. Saleh et al. [187] applied EPNs for controlling sugar beet fly *Pegomyia mixta* on sugar beet plants naturally infested. A single foliar spray of *S. feltiae* or *H. bacteriophora* caused 81 or 76% reduction in the larval population in infested leaves.

Entomopathogenic nematodes showed high efficacy in controlling insect pests in cryptic habitats especially tree borers. Abdelkawy et al. [180, 209] obtained up to 90% larval mortality by injecting *S. carpocapsae* or *H. bacteriophora* in galleries in trees infested with *Z. pyrina*. El Shazly et al. [182] conducted field evaluation of the efficacy of five Egyptian and imported entomopathogenic nematodes against *Z. pyrina* and concluded all nematodes were efficient against the larvae or the pupae of the pest. The best field result was obtained by *S. riobrave* (76% larval mortality) when injected at 2,000 IJs/ml in the galleries of the pest larvae in apple branches. In a study of Abdelkawy et al. [181] combinations of 4 nematodes and 3 application methods were applied in controlling *Z. pyrina* larvae in an apple orchard in Egypt. The three application techniques were spraying, injection, and soaking small cotton plugs with the nematode suspension and put them on the gallery openings. Before treatments the infestation level of *Z. pyrina* larvae in apple trees ranged from 29 to 134 larvae/3 trees. After 1 week of nematode application, mortality of larvae inside galleries ranged from 33.67 to 88.89% depending mostly on the application technique. The cotton ball technique achieved the best results followed by the injection technique.

Attempts of EPNs against larvae of red palm weevil tunneling inside date palm trunks seemed impractical or not economically feasible [210, 211]. When Saleh et al. [179] targeted the adults in soil around date palm trunks or the pupae in inside their cocoons aggregated in the leaf petioles, they obtained encouraging results. Mortality of prepupae and pupae inside these cocoons reached 98.3% due to *H. bacteriophora* and 90.4% due to *H indica* and 60.3% due to *S. carpocapsae*. Adult mortality in soil around date palm trunks reached 90% due to *Steinernema* or *Heterorhabditids*.

Application of *S. glaseri* in strawberry field against scarab beetles *Temnorhynchus baal* was applied by Shamseldean and Atwa [183] and recorded percentage of population reduction up to 96.8 and 99.1% after four and eight field applications, respectively. Abdel-Razek and Abd-Elgawad [184] sprayed the heads of cauliflower with *H. bacteriophora* and *H. indica* at concentration of 1,500 IJs/ml and obtained a reduction of up to 83.3 and 94.7% in the adult population of the hairy rose beetle *Tropinota squalida*. Saleh [185] sprayed a cabbage field with *H. taysearae* for controlling the cabbage worm *Piers rapae* and recorded a reduction pest population of 96.3 within 2 weeks.

In spring wheat, EPNs also had a significant effect as mentioned by El-Wakeil and Volkmar [178], who studied the efficiency of three EPNs species to control fruit fly in spring wheat. The results revealed that *H. bacteriophora* was more efficacious than *S. carpocapsae* against *Oscinella frit* in the laboratory, while the latter was more efficient in field experiments. In field experiments, *Steinernema carpocapsae* was more efficacious than *S. feltiae* and *H. bacteriophora*. Gaafar et al. [188] studied the efficacy of entomopathogenic nematodes (*H. bacteriophora* and *S. carpocapsae*) against chamomile stem weevil *Microplontus rugulosus* and chamomile smooth beetle *Olibrus aeneus;* they confirmed that EPNs had achieved a significant reduction of pest damage.

EPNs are effective not only against insect pests but also against plant parasitic nematodes as confirmed by Noweer and El-Wakeil [190], who conducted a field experiment for controlling plant parasitic nematode *Meloidogyne incognita* in tomato field using a combination between EPNs and trapping fungi. The mortality percentages were higher in combining EPNs and trapping fungi than either by trapping fungi or EPNs alone. Abd-Elgawad and Aboul-Eid [189] applied Egyptian isolated of *H. indica* and *H. bacteriophora* in a watermelon field infested by the parasitic plant nematode, *Meloidogyne incognita* and obtained a significant reduction in the plant nematodes after 1 week.

The following is an alphabetical list of natural enemies existed in Egypt and mentioned through this chapter (see Table 4).

4 Potential of Biological Control in Egypt

Agriculture contributes about 13% of the Egyptian gross domestic product (GDP) and over 30% of employment opportunities. Agriculture production has to increase by 7% shortly in order to face the population increase. This production increase should be achieved through the sustainable agriculture system which preserves the environmental recourses and limits the use of chemical pesticides in pest management programs. Therefore, biological control should be a main part of sustainable agriculture in Egypt in the nearest future. Biological control is defined as the use of beneficial organism (natural enemies) to control the agricultural pests. Natural enemies included parasitoids, predators and pathogenic organisms. Because of the growing consciousness about the hazards of traditional chemical pesticides to both human and environment, many countries have converted to biological control as alternatives to chemical control.

In a given country, biological control industry depends on many factors including infrastructure, personnel, equipment, and market. On the top of these factors are the three pillars of biological control, namely (1) abundance of the natural enemies, (2) mass production, and (3) the field application of natural enemies for biological pest control. Through this chapter these three pillars are discussed in detail in Egypt, examples of parasitoids, insect predators, predatory mites, and entomopathogenic nematodes are given. Of the most successful examples of biological control in Egypt, the control of the sugar cane borer *Chilo agamemnon* in Upper Egypt, where the egg parasitoids *Trichogramma evanescens* controlled this serious pest. *Trichogramma* has been successfully used in controlling the bollworms, *Pectinophora gossypiella Earias insulana*, and *Helicoverpa armigera* in north

Table 4 Alphabetical list of natural enemies existed in Egypt mentioned in this chapter

1. Parasitoids and predators	
1	*Aganaspis daci*
2	*Allotropa mecrida*
3	*Anagyrus kamali*
4	*Andrallus spinidens*
5	*Apanteles ruficrus*
6	*Aphidius colemani*
7	*Aphidius matricariae*
8	*Aphidius uzbekistanicus*
9	*Brachymeria femorata*
10	*Bracon brevicornis*
11	*Bracon hebetor*
12	*Callitiola* sp.
13	*Chartocerus* sp.
14	*Chrysoperla carnea*
15	*Coccinella septempunctata*
16	*Coccinella undecimpunctata*
17	*Coccophagus scutellaris*
18	*Camponotus* sp.
19	*Conomorium eremita*
20	*Coranus* sp.
21	*Cryptolaemus montrouzieri*
22	*Cydonia* sp.
23	*Diaeretiella rapae*
24	*Encarsia siphonini*
25	*Encarsia Sophia*
26	*Ephedrus persicae*
27	*Eretmocerus mundus*
28	*Harmonia axyridis*
29	*Labidura riparia*
30	*Mantis religiosa*
31	*Metaphycus* sp.
32	*Microplitis* sp.
33	*Nesidiocoris tenuis*
34	*Orius albidipennis*
35	*Orius laevigatus*
36	*Pediobius furvus*
37	*Platytelenomus hylas*
38	*Praon gallicum*
39	*Praon necans*
40	*Rhoptrmeris* sp.
41	*Rhynocoris fuscipes*
42	*Scutellista caerulea*

(continued)

Table 4 (continued)

43	*Scymnus interruptus*
44	*Tachina larvarum*
45	*Trichogramma evanescens*
46	*T. bourarachae*
47	*T. buesi*
48	*T. cordubensis*
49	*T. euproctidis*
50	*T. oleae*
51	*T. nerudai*
52	*Trioxys* sp.
2. Predatory mites	
53	*Agistemus exsertus*
54	*Amblyseius swirskii*
55	*A. cucumeris*
56	*A. enab*
57	*A. cydnodactylon*
58	*A. yousefi*
59	*Cunaxa capreolus*
60	*Euseius citrifolius*
61	*Neoseiulus barkeri*
62	*Neoseiulus californicus*
63	*Neoseiulus cucumeris*
64	*Neoseiulus idaeus*
65	*Phytoseiulus macropilis*
66	*Phytoseiulus persimilis*
67	*Raphignathus gracilis*
68	*Saniosulus nudus*
69	*Typhlodrompis swirskii*
3. Entomopathogenic nematodes	
70	*Heterorhabditids egyptii*
71	*Heterorhabditids indica*
72	*Heterorhabditids taysearae*
73	*Steinernema abbasi*
74	*Steinernema carpocapsae*
75	*Steinernema feltiae*
76	*Steinernema glaseri*
78	*Steinernema Kushidai*
79	*Steinernema riobrave*

Egypt. The predatory mites *Phytoseiulus persimilis* used successfully in controlling the two-spotted mite, *Tetranychus urticae* on vegetables in greenhouses of the agricultural investment companies. Entomopathogenic nematodes have been used in experimental field trials to control fruit tree borers, fruit flies, and plant parasitic nematodes.

Although Egypt possesses a large market for biological control products, the commercial products are still under market needs. Examples of the bio-control products that commercialized in Egypt are Bio-fly (*Beauveria bassiana*) against white fly; Bio-Zeid (*Trichoderma album*), Rhizo-in (*Bacillus subtilis*), Bio-arc (*Bacillus megaterium*) against fungal diseases. Mass production of insect predators is still in progress and needs higher technology in production and storage. It can be concluded that Egypt has the potential to promote its biological control and contribute more to sustainable agriculture.

5 Conclusions and Recommendation

About 80 species of natural enemies listed in this book chapter have been investigated by Egyptian biological control researchers (see Table 4). These natural enemies cover almost all the important agricultural pests of field crops, vegetables, fruit orchards, ornamentals, and greenhouse crops. It has been concentrated in this book chapter on abundance of natural enemies in the Egyptian environment and the attempts of mass production and field application of the most important natural enemies for the biological pest control. Examples of parasitoids, insect predators, predatory mites, and entomopathogenic nematodes were discussed in detail.

The results showed that one of the most successful examples of biological control was using egg parasitoid *Trichogramma* to control the sugar cane borer *Chilo agamemnon* in sugarcane in Upper Egypt. The same parasitoid species was released to manage the bollworms in cotton fields in Delta Governorates. The predatory mite *Amblyseius swirskii* and *Phytoseiulus persimilis* was also used successfully in controlling the two-spotted mite on vegetables in greenhouses of the investment companies.

As mentioned in this book chapter the biological control industry depends on many factors, including infrastructure, personnel, equipment and market, beside existence of the natural enemies in the local environment and attempts of mass production and field application of natural enemies for biological pest control. Egypt has most of these factors as shown through this chapter, what is still need the support of decision maker in the country are the infrastructure and some equipment. There is a growing awareness towards the hazards of agricultural chemicals and the need to the biological control for conserving the environment and realizing the sustainable agriculture in Egypt.

Egypt has a large market of biological products represented mainly by the agricultural investment companies which export these organic products of vegetables and fruit to Arab and European countries. With giving more support to the biological control infrastructure, mass production and field application technology, Egypt would have a cleaner environment with more stable system of sustainable agriculture.

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Impacts of Climate Change on Insect Pests of Main Crops in Egypt

Ali Ahmed El-Sayed, Mohamed Ahmed Nada, and Said Moussa Abd El-Fattah

Abstract Climate change is expected to have a negative or positive effect on the short and long term on the diversity of pest's abundance, pest's–host plant interactions, an abundance of natural enemies, and finally the extent of damage to the Egyptian economy due to the impact on agricultural economic crops. Under current and previous climatic conditions, major crops and their pests have adapted to climatic elements that help them to survive, grow, reproduce, and spread, based on host abundance and interaction. The significant change in climate is reflected in the increase in the average temperature of the globe, the change in precipitation amounts, their patterns, and their locations. These seasonal and long-term changes will affect the crops grown regarding production and components, the emergence of new plant species that were not previously known. In other words, any change in the components of the environment will be reflected in human lifestyles and the pests associated with their crops. In studies under laboratory conditions, climate components directly affected insect dynamics by modifying growth, survival, fertility, dispersion, and differentiation.

Keywords Agriculture, Climate change, Crops, Egypt, Insects

Contents

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1 Introduction

Egypt is located in the northeast corner of the continent of Africa. It is located on the Tropic of Cancer and passes between latitudes 22° and 36° 31′ north and longitude between 24° and 37° east of Greenwich. It has a total area of 1,001,450 km^2. The country stretches 1,105 km from north to south and, moreover, up to 1,129 km from east to west. It is bordered on the north by the Mediterranean Sea. On the east, it is by the Gaza Strip, Israel, and the Red Sea. In the south, it is by Sudan and in the west by Libya. Egypt is predominantly desert and arid and semiarid rangelands. Egypt can be divided into four major physical regions: the Nile Valley and Delta, Western Desert, Eastern Desert, and Sinai Peninsula. Egypt is known to be one of the oldest agricultural civilizations. The Nile has allowed the stable agricultural community to develop for thousands of years. The majority of the population is rural (estimated at 58% of the rural population); according to the Factbook, the July 2011 population was estimated at 82,079,636 with a growth rate of 1.96%. It is expected that the population census of Egypt in 2050 is about 165 million people, according to the Central Agency for Public Mobilization and Statistics. It is well known that Egypt has no effective rainfall except in a narrow band along the northern coast. Consequently, it has only the Nile River as the main source of water supply. The water-sharing treaty governs the availability of a reliable water supply from the Nile River to be 55.5 billion cubic meters per annum allocated to Egypt. The size of the available water resources is around 68 billion cubic meters, of which about 85% per year is used in agriculture, 9.5% in industry, and 5.5% in drinking. Egypt aims to develop its water resources over the next 40 years, especially since the per capita water is of 700 cubic meters per year. It is expected to fall to less than 350 cubic meters per year by 2050, to avoid steadily widening food gap, with the increase in the number of population, as well as the expected impacts of climate change. In the world population, it is projected to increase from about 7 billion in 2011 to 9.2

billion in 2050. The current rate of increase is about "six million per month, with almost all growth occurring in developing countries where natural resources are already under great stress. The Green Revolution technology led to doubling of food production between 1950 and 2010, with only a 10% increase in the area under production" [1]. However, meeting the food demand of the growing population and rising standards of living and changes in diet preferences will necessitate an additional 70% increase in production between 2010 and 2050 [2]. Grain yields of wheat [3] and rice [4] are sensitive to high temperatures [5].

Climate change resulting from the continuous emission of anthropogenic emissions of greenhouse gases affects the natural and human systems and sectors throughout the world, and changes so far may only be profound changes in the future. Some consider that action on climate change should have been delayed because of uncertainty about the precise nature, extent, and rate of changes in intervention. Others believe that the response to climate change is now necessary precisely because of uncertainty. In any case, the potential for significant changes in agroecosystems requires us to anticipate the potential impacts of climate change, to study how regions and farming systems adapt to those that cannot be avoided, and to identify how climate change mitigation can be mitigated to minimize its final impacts [6].

Climate change in different parts of the world has shown that it is likely to vary significantly from place to place. For example, in some areas rainfall will increase, and in other areas it will decrease. Not only is there a significant amount of variation in the nature of the possible change, but there is also a variance in the sensitivity of the different systems of climate change. Different ecosystems, for example, will respond very differently to changes in temperature or precipitation. There will be a few impacts of climate change likely to be positive so far as humans are concerned. For example, in parts of Siberia, Scandinavia, or Northern Canada, rising temperatures will tend to lengthen the growing season with the possibility of these areas to grow the most extensive variety of crops. Also, in the winter there will be reduced mortality and heating requirements. Moreover, in some places, increasing carbon dioxide helps the growth of some plant species leading to increased crop productivity. However, because, for centuries, human societies have adapted their lives and activities to the present climate, most climate changes will tend to produce a negative impact. If changes occur quickly, rapid and possibly costly adaptation to the new climate will be required by the affected community. It may be a substitute for the affected community to migrate to the region, where less adjustment will be needed, a solution that has become increasingly difficult or, in some cases, impossible in a busy world to talk.

Climatic change plays a vital role in the agriculture crop production and the pests and natural enemies associated. In crops, the potential effects are represented in growth periods and crop water requirements that depend on weather conditions in a site, whereas on the insects associated, the potential effects are in insect pests distribution, insect number of generations, infestation, outbreaks, and insect overwintering or summer survival [7–10]. The work aims to study the following points:

2 Climate Changes

The characteristic weather conditions of the atmosphere reflect the lower surface of the earth in a particular place, weather fluctuation to date under these conditions in the same location. Variables commonly used by meteorologists to measure daily weather events are air temperatures, such as rainfall, rain, frost, snow, cold, air pressure, humidity, wind, sunlight, and clouds. Climate changes can refer to (a) long-term changes in average weather conditions (*World Meteorological Organization usage*); (b) all changes in the climate system, including the drivers of change, the changes themselves, and their effects (*Global Climate Observing System usage*); or (c) only human-induced changes in the climate system (*United Nations Framework Convention on Climate Change usage*). "Climate change as referred to in the observational record of climate occurs because of internal changes within the climate system or in the interaction among its components, or because of changes in external forcing, either for natural reasons or because of human activities" https://climate4all.wordpress.com/2011/05/02/climate-waffles/. It is not possible to make clear attributions between these causes. Projections of future climate change reported by the Intergovernmental Panel on Climate Change (IPCC) consider the influence on the climate of only anthropogenic increases in greenhouse gases and other human-related factors (IPCC usage) [11]. According to the IPCC [12], climate change is any "change in climate over time whether due to natural variability or as a result of human activity." It is a consensus among IPCC researchers that increases in atmospheric concentrations of greenhouse gases (mainly CO_2, CH_4, N_2O, and O_3) since preindustrial times have led to a warming of the surface of the earth. During the last 250 years, "the atmospheric concentrations of CO_2, CH_4, and N_2O have increased by 30%, 145%, and 15%, respectively. The emissions are mainly due to the use of fossil fuels, but changes of land use as well as agriculture are also major sources of emissions" [13].

Therefore, climate change is a significant and permanent change in the statistical distribution of weather patterns over periods ranging from decades to millions of years https://worldclimatechange101.weebly.com/. There may be a change in average weather or in the distribution of weather around standard conditions, i.e., more or fewer extreme weather events. Climate change is caused by factors that include oceanic processes such as oceanic circulation. Variations in solar radiation that is received by Earth and plate tectonics and volcanic eruptions. Also, human-induced alterations of the natural world. These latter effects are currently causing global warming, and climate change is often used to describe human-specific impacts https://www.triviacountry.com/458-Hard-Climate-Change-Trivia-Questions.htm.

3 Climate Change in Egypt

The whole country is part of the great desert belt that stretches from the Atlantic Ocean across entire North Africa through the Arabian Peninsula. Egypt is characterized by hot climate and little rain. The average annual rainfall in all parts of the country is about 10 mm only. Even along the narrow northern strip of the coastal land of the Mediterranean where most rain occurs, the average rainfall is usually less than 200 mm, and the amount of precipitation is very rapidly inland (south). Rainfall calculations are meager for the fact that the bulk of Egypt is a barren and barren desert. Only across the Nile is a regular supply of ample water guaranteed, coming from the highlands hundreds of kilometers to the south. This is directed by artificial channels on a narrow strip of glacial soil on either side of the river, the Fayoum depression and the Delta. These areas of fertile land, which cover less than 3% of the total area of Egypt, support the population density [4, 9].

The average population density in the agricultural land in Egypt is more than 600 people km^2, while in the vast desert areas, which represent more than 97% of the total area, there is only one population 7/km^2. Nile River, thus, is a prominent geographical feature that has formed not only the physical spaces of Egypt but also the history and nature of human settlements [14]. Herodotus (484–425 BC) states that "Egypt is the Gift of the Nile." This is very true as the Nile gave Egypt, out of all regions of the vast North African Sahara, fertility that made possible not only the development of the famed ancient agricultural civilization but also the growth of this civilization in peace and stability [15].

3.1 Climate Change and Agriculture

The natural greenhouse effect raises the temperature of the planet to 33°C, thus making it habitable. On average, 343 W/m^2 of sunlight fall on the earth, roughly 1/3 of which is reflected back into space. The other 2/3 reaches the ground, which reradiates it as a longer wavelength, infrared radiation. Some of this is blocked by greenhouse gases, thereby warming the atmosphere. Naturally occurring greenhouse gases include water vapor, CO_2, methane (CH_4), and nitrous oxide (N_2O). Reducing emissions of CO_2 could be achieved by switching to renewable energy [16]. Nature provides freshwater through the hydrologic cycle. The process is as follows: production of vapors above the surface of the liquids, the transport of vapors by winds, the cooling of the air-vapor mixture, condensation, and precipitation [17].

In fact, the climate is a primary determinant of agricultural productivity. In contrast, food and fiber production are necessary to sustain and promote human well-being. Therefore, agriculture has been a significant concern in the discussions on climate change. The climate change in food supply is changing in two different ways affected. First, food supplies may be exposed to the future direct threat due to climate change. Second, the ability of the food supply may change efforts to reduce greenhouse gas emissions at a time when the community is trying to mitigate the effects of climate change in the future. The agricultural and economic impacts of climate change depend primarily on two factors: (a) the rate and magnitude of change in climate attributes and the agricultural effects of these changes, the rate and size of change in climatic features, and the agricultural impacts of these changes and (b) the ability of agricultural production to adapt to changing environmental conditions [18].

Climate is the most crucial factor in determining agricultural productivity, mainly through its effects on temperature and water systems. For example, the physiological limits of the major biomes are determined by the average annual temperature and soil water systems. It is therefore expected to alter the physical climate and physical environment of the crops growing change and affect the productivity of the agricultural biomass and yield [19].

It may be associated with the positive effects of fertilization effects enrichment CO_2, an increase in the duration of planting seasons in the upper latitudes and mountain ecosystems, and the potential increase in soil water availability in areas with an increase in annual rainfall. Each increase of 1°C in temperature may lead to an increase of 10 days in the growing season in northern Europe and Canada. The effect of CO_2 fertilization is real. However, the net positive effect can be controlled by other factors, such as the depth of effective rooting and the availability of nutrients. Moreover, productivity per unit of available water is expected to increase by 20–40% [20]. Adverse effects of projected climate change on agriculture may be due to increases in respiration rate as temperature raises with attendant decreases in net primary productivity (NPP). Of potential impacts; increases in the incidence of pests and diseases; shortening of the growing period in some areas. There is a decrease in water availability as rainfall patterns change and poor vernalization, whereas increased risks of soil degradation are caused by erosion. "The yield of rice has been estimated to decrease by 9% for each 1°C increase in temperature, using the explicit planetary isentropic coordinate (EPIC) model to examine the sensitivity of corn and soybean yields to climate change, projected a 3% decrease in both corn and soybean yields in response to a 2°C increase in temperature from a baseline precipitation level" https://www.climate-policy-watcher.org/agriculture-organization/climate-and-agri. However, a 10% precipitation increase balanced the adverse effect of a 2°C temperature increase. The effects of climate change on crop yields may be more harmful at lower latitudes and generally positive at middle and high-middle latitudes. Furthermore, crop growth is more influenced by extremes of weather than by averages. The annual mean of changes in temperature or precipitation used in most predictive models does not reflect the short-term effects of so-called extreme events such as droughts, floods, freezes, or heat waves [21, 22].

4 Effect of Climate Changes, Environmental Air Temperatures on Organism's Need for Heat and Accumulated Heat Units

Environmental air temperatures affect the evolution of biological organisms that do not regulate internal temperature, including crops and crop pests. Organism's development depends on the heat in the surrounding environment. To calculate the organism's need for heat, the environmental air temperatures are converted to heat units by some equations. The organism needs a certain amount of heat to its evolution from a point in its life cycle to another which is called the heat units (HUs). Whereas, the amount of heat units required for the entire life cycle of the organism are called accumulated heat units (AcHUs). Moreover, thus, the future change in environmental air temperature has potential effects on commercial plant crops and associated pests. It is likely that moderate and cold climates will become more suitable for the growth and reproduction of some crops and their pests. A gradual increase in air temperatures will be lead to potential favorable environmental conditions to suit early in the cultivation of some economic crops such as cotton will become more responsive to growth. Given the length of time needed for growth, there is a strong possibility to increase the number of generations of their pests associated with them and with the possibility of more severe epidemics.

Under Egyptian conditions a study was carried out on the future potential effect of climate changes on the growth pattern of cotton plants infested with pink bollworm, *Pectinophora gossypiella* (Saund) (PBW), compared to a current study for four seasons of 1999–2002 [23].

4.1 On Accumulated Heat Units

Figure 1 shows an average number of accumulated heat units (AcHUs) through the study periods of 1999–2002 years and the predicted during 2025, 2050, 2075, and 2100 years in Egypt. It recorded 3,814, 4,071, 4,250, 4,403, and 4,529 units from the 1st of January until the end of December for the current and predicted years, respectively. It increased in the predicted years than the current study periods with 257, 436, 589, and 715 units, respectively (Table 1). These increases of AcHUs will be expected to effect on all environmental components biotic factors, animals, plants, etc.

4.2 On Five Cotton Sowing Dates

Data in Table 2 show the observed number of Julian days and an average number of AcHUs (from fixed date of Jan. 1) required for the five cotton sowing dates on the

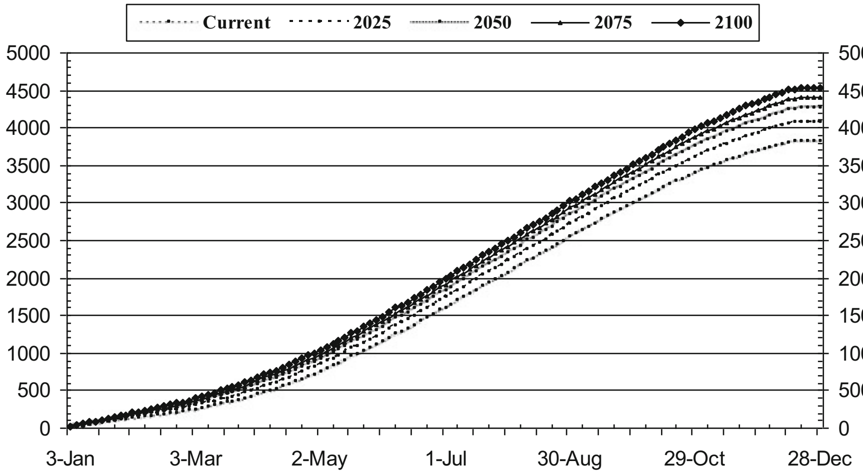

Fig. 1 Average number of accumulated heat units through the study periods of 1999–2002 and the predicted during 2025, 2050, 2075, and 2100 years

Table 1 Average numbers of accumulated heat units through the study seasons of 1999–2002 and the predicted during 2025, 2050, 2075, and 2100 seasons

Seasons	AcHUs	Increasing	Seasons	AcHUs	Increasing
1999–2002	3,814	–	2075	4,404	590
2025	4,072	258	2100	4,529	715
2050	4,251	437			

four cotton seasons (1999–2002) and the expected of Julian days in 2025, 2050, 2075, and 2100. Julian days for the five sowing dates were 74, 84, 95, 105, and 115 days with an average of 94.6 ± 16.3 days, and average AcHUs were 285 ± 37, 338 ± 54, 422 ± 70, 521 ± 62, and 623 ± 68 units, respectively, with the general average of 438 ± 136.5 unit. In over the four expected cotton seasons comparing to the four cotton seasons of 1999–2002, the physiological time required for the occurrence of the phenomena of Julian days for the first cotton sowing dates was the lowest, while the fifth one was the most significant. The periods of days required for the expected four cotton seasons were less than in the observed. The periods required for the expected on 2025 over the five sowing dates were more significant than in 2100; the period in days decreased gradually from 2025 to 2100 cotton seasons.

Table 2 Comparing the number of days from Jan. 1 required for the five cotton sowing dates during 1999–2002 seasons with the predicted in 2025, 2050, 2075, and 2100 cotton seasons

[a]Observed number of days and AcHUs during 1999–2002 seasons				Number of days in predicted cotton season							
Sowing dates		AcHU		2025		2050		2075		2100	
Sowing date	Julian days	Average	Sd[b]	Julian days	[c]Red. % in days	Julian days	Red. % in days	Julian days	Red. % in days	Julian days	Red. % in days
1st	74	285	37	63	14.9	58	21.6	52	29.7	48	35.1
2nd	84	338	54	71	15.5	65	22.6	60	28.6	56	33.3
3rd	95	422	70	83	12.6	76	20.0	71	25.3	66	30.5
4th	105	521	62	94	10.5	88	16.2	82	21.9	78	25.7
5th	115	623	68	105	8.7	98	14.8	93	19.1	89	22.6
General average	94.6	438		83.2		77		71.6		67.4	
Sd	16.3	136.5		16.9		16.3		16.5		16.5	

[a]Observed: number of days and average number of accumulated heat units (AcHUs) from Jan. 1 occurred for the five sowing dates during 1999–2002 cotton season

[b]*Sd* standard deviation

[c]Reduction percentages in days than observed of the five sowing dates during 1999–2002 = Julian days ((Observed − predicted)/observed) × 100

4.3 On the Phenomenon Occurrence of 50% of Plants Carrying Cotton Fruit Structures

Table 3 shows that the duration of days and AcHUs for the phenomenon were calculated from sowing dates. The duration as the average to the four cotton seasons (1999–2002) was ranged between 57.0 ± 4.1 and 41.4 ± 0.9 days with a range of 15.6 days. The most massive reduction in days was 2100 cotton season. The compensation from observed in 2100 was 9 days at the first sowing date while reduced to 4.4 days at the fifth one. The highest compensation was found on the first sowing date, whereas the lowest at the fifth one. The average days required to the occurrence of the same phenomenon for the first sowing date were 57.0 ± 4.1 days in the observed compared to 48 days for the expected 2100 season whereas at the fifth one were 41.4 ± 0.9 days in the observed compared to 37 days for the expected 2100 season. The physiological time required for the occurrence of the phenomena was decreased by 9.0–4.4 days over the five sowing dates at 2100 season; it cleared that the cotton plant can get the heating unit required in short time.

4.4 On the Presence of Green Cotton Bolls Preferred for Pink Bollworm Larvae

Data in Table 4 is a comparison between the averages of days, 1999–2002 cotton seasons, required to occur green cotton bolls preferred for infestation with PBW larvae and which will be expected in 2025, 2050, 2075, and 2100 cotton seasons, calculated from the five sowing dates. The first dates of cultivation had been highly reduced, but the latest was the lowest one. The periods required for occurring green cotton bolls preferred for infestation with PBW decreased at the previous predicted years which the most substantial reduction was in 2100 cotton season. The physiological time required for the occurrence of the phenomenon was decreased over the five sowing dates at 2100 season; it cleared that the cotton plant can get the heating unit required in short time.

5 Climate Change and Pests

More than 10,000 species of insects, 600 weeds, and 1,500 fungi, as a typical pest name, adversely affect daily human life. They reduce the quality and quantity of food produced, by reducing production and destroying stored products and competing with humans for food and causing many diseases for humans, animals, and crops. Humans began to control the pests at the same time they started farming. Over the years, many pest management systems have been implemented: manual removal of grasses and animal pests, poor crop separations, mechanical soil treatment,

Table 3 Comparing the observed average number of days from the sowing dates needed for the occurrence of 50% of cotton plants carrying fruits with the predicted ones in 2025, 2050, 2075, and 2100 cotton seasons

		[a]Observed periods and AcHUs during 1999–2002 seasons				Predicted cotton seasons							
Sowing date		Days		AcHU		2025		2050		2075		2100	
Sowing date	Julian days	Average	Sd[b]	Average	Sd	Days	[c]Com.	Days	Com.	Days	Com.	Days	Com.
1st	74	57.0	4.1	525	24	53	4.0	50	7.0	49	8.0	48	9.0
2nd	84	51.6	3.3	528	9	48	3.6	46	5.6	45	6.6	44	7.6
3rd	95	47.6	2.3	533	17	45	2.6	43	4.6	42	5.6	41	6.6
4th	105	44.6	2.4	530	28	41	3.6	40	4.6	39	5.6	38	6.6
5th	115	41.4	0.9	524	25	39	2.4	38	3.4	37	4.4	37	4.4
Range	41	15.6		9		14		12		12		11	

[a]Observed: average number of days and accumulated heat units (AcHUs) from the five sowing dates during 1999–2002 cotton seasons
[b]*Sd* standard deviation
[c]*Com.* compensation is the period which the plant can save than observed period during 1999–2002 seasons

Table 4 Comparing the observed average number of days from the sowing dates needed for occurring the green cotton bolls preferred for infestation with predicted in 2025, 2050, 2075, and 2100 cotton seasons

Sowing date		[a]Observed periods and AcHUs during 1999–2002 seasons				Predicted cotton seasons							
		Days		AcHUs		2025		2050		2075		2100	
Sowing date	Julian days	Average	Sd	Average	Sd[b]	Days	[c]Com.	Days	Com.	Days	Com.	Days	Com.
1st	74	106.6	3.8	1,222	8	100	6.6	97	9.6	95	11.6	93	13.6
2nd	84	101.4	3.6	1,241	26	96	5.4	93	8.4	91	10.4	89	12.4
3rd	95	96.0	2.6	1,243	39	91	5.0	89	7.0	87	9.0	85	11.0
4th	105	92.6	2.9	1,248	35	87	5.6	85	7.6	83	9.6	82	10.6
5th	115	88.4	2.6	1,248	35	84	4.4	82	6.4	75	13.4	80	8.4

[a]Observed: average number of days and accumulated heat units (AcHUs) from the five sowing dates during 1999–2002 cotton seasons
[b]*Sd* standard deviation
[c]*Com.* compensation is the period which the plant can save than observed period during 1999–2002 seasons

biological pest control, genetic engineering, and the use of chemical pesticides. In all available pest management systems, pesticides have become the most preferred alternative to pest control.

Bearing in mind these adverse effects, researchers in the 1960s began developing a different approach to pest control called "Integrated Pest Management" (IPM). The IPM approach calls for the conservation of pests at economically acceptable levels through a variety of control strategies that discourage pests, promote beneficial predators or parasites that attack pests, and use pesticides at a time that coincides with the period most susceptible to insect life cycles. "However, even with integrated pest management, pesticides are often the only way to deal with outbreaks of emergency pests" [24]. Therefore, agriculture may be able to limit inputs from pesticides, but currently economically eliminated is not possible. While political leaders, citizens, and government officials try to mediate and resolve conflicts between the risks and benefits of using pesticides by producing safer chemicals, selective pesticides, better application methods, and stronger pesticide acceptance rules, these conflicts, are likely to expand climate change.

5.1 Climate Change and Insects

Climate and weather can significantly affect the development and distribution of insects. Current estimates of climate changes are estimated to rise in annual global mean temperatures of 1°C by 2025 and 3°C in the next century. These temperature increases have a number of effects on temperature-dependent insects, especially in the Central European region. Changes in the climate may lead to changes in geographical distribution, and, in most cases, changes in population growth rates increase the number of generations and extension of the development season. Changes in the climate may be changes in the synchronization of crops and pests between phenology, changes in species interactions, and increased risk of invasion by migratory pests [25, 26].

In the context of climate changes predicted by the Goddard Institute for Space Studies General Space Studies model, it is estimated that northward shifts in the potential distribution of the European maize digger reach 1,220 km, with an additional generation in almost all regions where there is currently known to occur [26].

Climate variability in decimal scales affects the timing and intensity of insect outbreaks that may alter species distribution [27]. It uses spatial modeling techniques to infer how sustainable climate change may alter the geographical distribution of species. Using simulation, a series of maps were produced showing projected shifts in areas where species examined by their range could be examined if typical climatic conditions persisted at annual and nodal intervals. The relationship between temperature tolerance and phenology of insects was studied by Klok and Chown [28]. They defined how current climate change like increased temperature and decreased rainfall affects on physiological regulation and susceptibility.

It should be noted that the impact of global climate change on plant and pest populations depends on the combined effects of climate (temperature, precipitation, and humidity) and other components such as soil moisture, atmospheric carbon dioxide, and tropospheric ozone (O_3). It can be changed in agricultural productivity due to the direct effects of these factors on the plant level or spillover effects on the system level, for example, through shifts in the incidence of insect pests. With regard to crops, data suggest that rising CO_2 may have many positive impacts, including yield stimulation, improved resource efficiency, more successful competition with weeds, reduced O_3 toxicity, and, in some cases, better resistance to pests and diseases. However, in a warmer climate, many of these beneficial effects may be partially or totally lost. Warming accelerates plant development, reduces grain filling, reduces nutrient efficiency, increases crop water consumption, and favors weeds on crops. Also, the rate of insect evolution can be increased [29].

5.2 Impact of Climate Change on Overwintering Survival

Diapause is a period of suspended developmental activities, the manifestation of which is governed by environmental factors like temperature, humidity, and photoperiod. Diapause plays a vital role in the seasonal regulation of insect life cycles because of which the insects have a better advantage to survive a lot of environmental adversities. Increase in the winter temperature was increase in the survival of overwintered insects in Egypt such as pink bollworm, *P. gossypiella*. The diapaused larvae of the pink bollworm pass the winter in the bolls, in cotton seeds, in the trash in fields or at gins, or in cracks in the soil. Earlier larvae of the pink bollworm entered diapaused in the fall; the adults emerged earlier. The beginning and end of moth's emergence differed according to the time in which larvae entered diapause. The peaks of moths' emergence from all dates of starting diapause were detected during the 2nd and 3rd weeks of May [30], so the pink bollworm changed his behavior and infested the leaf pedicel of cotton plants before appearing the square (Fig. 2).

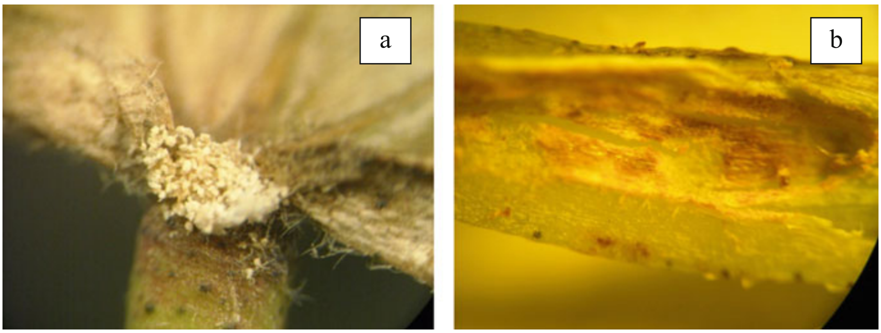

Fig. 2 Pink bollworm larvae poured in the leaf of the cotton plant, (**a**) faces of larvae and (**b**) the tunnel

The average durations of diapaused larvae of the pink bollworm under natural conditions were decreased gradually, being 161, 136, and 94.8 days from larvae entered diapause in September, October, and December, respectively [31]. The average duration of the resting larvae was inversely proportional to temperature at any age of that stage. Moth's emergence of the first peak, overwintered as diapause larvae, depended on accumulated heat units from a fixed date, Jan. 1, and occurred over the last third of May. While, at the expected seasons, the first peak of moth's emergence occurred early about a month, over at the last third of April on 2100 season (Fig. 3) [23]. Increasing temperatures, from 1.5 to 2.5°C, would substantially increase winter survival and extend the range of *P. gossypiella* northward into the San Joaquin Valley ([32], Fig. 4b, c, e, f). The full-grown larvae of the last generations of *Sesamia cretica* Led., *Chilo agamemnon* Bles, and *Ostrinia nubilalis* (Hbn) were overwintered inside the corn stalks or below the soil level inside corn roots. The manipulation of cotton and maize planting dates may be avoiding the attack of first-generation moths emerging from diapause. Higher temperatures were accelerated metabolic rates and shorten the period of insect diapause due to faster depletion of stored nutrient resources [33]. Insects have limited ability of homeostasis with external temperature changes. So they have developed a range of strategies such as behavioral avoidance through migration and physiological adaptations like diapause to support life under thermally stressful environments [34]. As an adaptive trait, there are two main types of insect diapause: estivation and hibernation to sustain life under high- and low-temperature extremes, respectively [35].

Warming in winter months may cause a delay in diapause and early faster termination of diapause in insects. Increase in temperature in the range of 1–5°C would increase insect survival due to low winter mortality [36, 37]. *Helicoverpa*

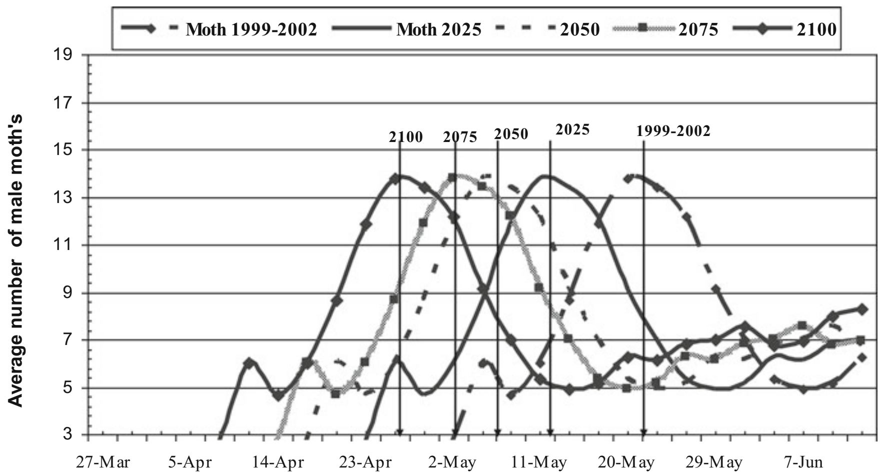

Fig. 3 The peak of the pink bollworm moth's emergence, from the diapause larvae, occurred through the study seasons 1999–2002 in the last third of May and in the predicted seasons 2025, 2050, 2075, and 2100

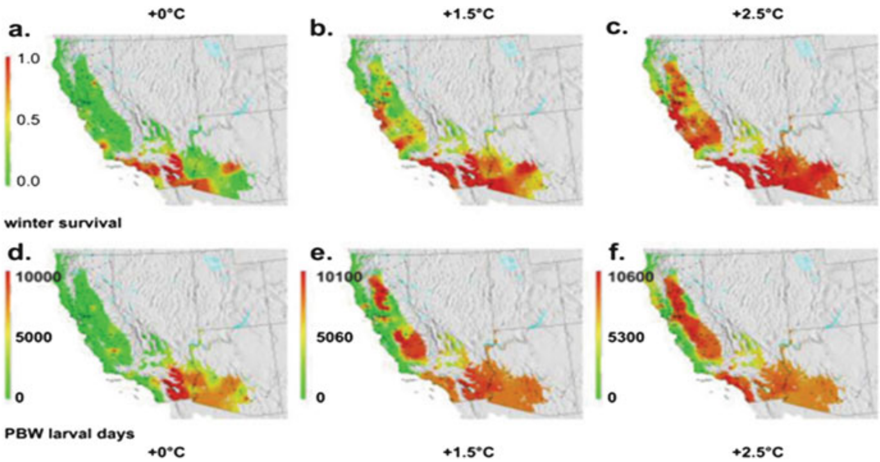

Fig. 4 Winter survival of PBW larvae (**a**–**c**) and cumulative PBW larval days per plant (**d**–**f**), respectively, during 2003 across the ecological zones of southern Arizona and California: (**a**, **d**) observed weather, (**b**, **e**) 1.5°C increase in average daily temperature, and (**c**, **f**) 2.5°C increase in average daily temperature (From Gutierrez et al. [32])

armigera (Hubner), a major pest of cotton, maize, and vegetables in Egypt, is predicted with the degree days required [38]. *H. armigera* entered diapause as pupae at 15°C, and the moth emerged after 251 days under laboratory conditions [39].

5.3 *Climate Change and Increase in the Number of Insect Generations*

Generation is the period from any given stage in the life cycle to the same stage in the offspring. The temperature and availability of food are two key factors that may influence the generation time. Temperature increase between upper and lower limits may accelerate the rates of development, reproduction, and survival of insects. During summer the insect generation time was shorter, but during winter the generation time was elongated. The *H. armigera* had three to five generations from March until November in Egypt [40–42]. The predicted peaks of generations could be detected when the accumulated heat units recorded 558.18 DDs [43]. The cotton leafworm, *Spodoptera littoralis* (Boisd.), is a polyphage insect fed on many crops, vegetables, and weeds in Egypt causing more damage. The *S. littoralis* was active all over the year and has many generations at the year. Increase in temperatures, the generation time of *Spodoptera litura* would decrease by 18–22% and subsequently increase number of generations. The development rate of *S. litura* immature stages was increased linearly as a function of temperature until approximately 34–36°C, after which it became nonlinear. Under the extreme temperature of

38°C, larval and pupal stages of *S. litura* had no development to the next stage. Females could not deposit eggs at 15°C and >35°C [44]. Male moths of *P. gossypiella* captured in pheromone traps indicated the presence of five to six generations a year. The number of male moths varied from year to another and even during the same season. This may be due to the moth's emergence from larval diapause which was affected by weather factors and crop rotation. *P. gossypiella* was three to five generations during the period extended from March to December [30, 45]. Five peaks of *P. gossypiella* males' flight activity were recorded in seasons 1989 and 1990, during July, August, September, October, and November [46]. The seasonal activity curves and the moth's population linear curves indicated those four generations were evident during fruiting and flowering stages and periods in both seasons. Constant temperatures of 32–35°C or higher and fluctuating temperatures with a mean of 32°C or higher resulted in the reproductive failure of *P. gossypiella* moths if exposed during the larval and pupal or adult stages. This failure usually occurred because males that were exposed to high temperature did not mate or efficiently transfer sperms to the spermatheca of the female, or both [47–49]. "Insects will be capable of completing more number of generations per year, and ultimately it will result in more crop damage" [50, 51].

5.4 Impact of Climate Change on Natural Enemies

Biological control of insect pests is one of the essential components of integrated pest management. Climate change will lead to a shift in the cultivation of crops such as cotton that was planted after wheat at the end of April until the end of May; it affected the balance between cotton insect pests and their natural enemies.

In Egypt, during the past years some trials use the natural enemies (*Trichogramma* spp.) in controlling some pests such as bollworms on cotton and Lepidoptera pests on sugar cane. The mass rearing of *Trichogramma* spp. was started in 1992 in the Cotton Bollworms Department, Plant Protection Research Institute, Agriculture Research Center. In the year 2003, the Ministry of Agriculture and Land Reclamation established 15 labs in Egypt for mass production and release of the parasitoid to control the cotton bollworms and other pests. The use of *Trichogramma* spp. in controlling bollworms reduced insecticidal application [52, 53]. Under simulating field conditions in Egypt, *T. evanescens* was susceptible to a temperature between 35 and 40°C which reduced the adult emergence rate and fecundity and can be made the releasing card from substances that avoid the parasitoid from unfavorable temperature [54]. Natural enemies of insect pests (predators, parasitoids, and pathogens) are prompt density responsive in their action subjected to the action of biotic and abiotic components. Changes in temperature will also alter the timing of diurnal activity patterns of different groups of insects [55], and changes in interspecific interactions could also alter the effectiveness of natural enemies for pest management [56]. The insect may pass life stages more quickly at higher temperatures, reducing the window of chance for parasitism to the survival and multiplication of parasitoids [51, 57]. Temperature affects the rate of insect development but also has a profound effect on fecundity and sex ratio of parasitoids [58, 59]. Natural enemies of the insect pests are more sensitive to the climatic changes. Populations of insects and their natural enemies may respond differently to climate changes. Precipitation changes can also affect the relation between natural enemies and their insect. Incidence entomopathogenic fungi might be favored by prolonged humidity conditions and be reduced by drier conditions [60]. The relationship between insect pests and their natural enemies under the climate change needs to be studied carefully to devise appropriate methods for using natural enemies in integrated pest management.

Relationships between insect pests and their natural enemies will change as a result of global warming, resulting in both increases and decreases in the status of individual pest species. Quantifying the effect of climate change on the activity and effectiveness of natural enemies for pest management will be a major concern in future pest management programs. The majority of insects are benign to agroecosystems, and there is considerable evidence to suggest that this is due to population control through interspecific interactions among insect pests and their natural enemies – pathogens, parasites, and predators [61]. Oriental armyworm, *Mythimna separata* (Walk.), populations increase during extended periods of drought (which is detrimental to the natural enemies), followed by heavy rainfall because of the adverse effects of drought on the activity and abundance of the natural enemies of this pest [62]. Aphid abundance increases with an increase in CO_2 and temperature; however, the parasitism rates remain unchanged in elevated CO_2. Temperatures up to 25°C will enhance the control of aphids by Coccinellids [63]. The interactions between insect pests and their natural enemies need to be studied carefully to devise appropriate methods for using natural enemies in pest management.

5.5 *Impact of Climate Change on Insect Population Dynamics and Outbreaks*

The distribution and abundance of insects and their host plants are determined by species-specific climate requirements for their growth, survival, and reproduction. Changes in climate will determine the future distribution, survival, and reproduction of the insects [64]. The differential rates of range adjustments between annual and perennial plant species along with local extinctions will definitely affect distribution and survival of insect fauna associated with them [65]. Altitude wise shifts in insect distributions along with their host plants in response to changing climate are already in progress. With the rise in temperature, the insect pests are expected to extend their geographic range from tropics and subtropics to temperate regions at higher altitudes along with shifts in cultivation areas of their host plants [37, 56, 66–68]. This may lead to an increased abundance of tropical insect species [69, 70], and sudden outbreaks of insect pests can wipe out certain crop species, entirely [71]. At the same time, warming in temperate region may lead to decrease in relative abundance of temperature-sensitive insect population [37, 51, 66]. Mostly the polar regions are constrained from the insect outbreaks due to low temperature and frequently occurring frosts [72]. In the future, projected climate warming and increased drought incidence [68] are expected to cause more frequent insect outbreaks in temperate regions.

Increased temperature will affect the abundance of insect pests through geographic range expansion, increased overwintering survival, and more number of generations per year, thereby increasing the extent of crop losses. It may result in upsetting ecological balance because of unpredictable changes in the population of insect pests along with their existing and potential natural enemies [73, 74].

The cotton mealybug, *Phenacoccus solenopsis* Tinsley, has recently emerged as a serious insect pest of many crops in Egypt and caused yield losses. The first record of this insect was at 2009 on weeds and after that was a geographic distribution in many areas of Egypt, and many new host plants were recorded during the view last years. This outbreaks may be due to increasing of temperature and relative humidity during the summer months [75]. Among the recorded 22 species of host plants for *P. solenopsis* belonging to 12 families are Malvaceae, Tiliaceae, Portulaceae, Solanaceae, and others. Eight species of herbal host plants were recorded as a new record in Egypt for the first time. The lower developmental temperature for *P. solenopsis* was 8.2°C, and degree days were 774.1 DDs for the generation. Based on the degree days requirements, the number of annual generations was 7.143 when the average annual temperature was 23.29°C [76]. The mean temperature was the most important environmental variable determining the potential geographic distribution of *P. solenopsis* [77]. Losses in cotton yield due to the mealybug varied between 35 and 32% in India [78].

P. gossypiella captured in the USA in pheromone traps was greatly reduced at temperature $<18.1°C$ and also reduced at moderate temperature only on windy nights and less affected by wind at temperatures $>22°C$. Temperature and wind affected dispersion of the pheromone plume and subsequently affected the pheromone trap catch. The peak time of *P. gossypiella* male moths' capture was correlated significantly with times of sunset, sunrise, and wind speeds falling below 2.68 m/s, minimum temperature of the same and previous nights and maximum temperature in California, USA. Minimum night temperature, wind speed fell below 2.68 m/s, and moon age provided a good fit [79, 80].

5.6 Climate Change and Insect Migration

Abiotic and biotic factors continue to have a considerable impact on migratory species. In Egypt, some Lepidoptera pests were migrated from parts to another according to a temperature such as *Agrotis ipsilon* and caused series damage to crops and vegetables. *H. armigera* was migrated from the around counters to Egypt and caused severe damage to crops and vegetables and resistance to insecticides. Low levels of genetic differentiation among Turkish, Israeli, Egyptian, and Ethiopia populations were revealed, suggesting a high degree of gene flow; it suggests that there are migratory flights of *H. armigera* within this countries [81]. Range extension in migratory species like *H. armigera*, a major pest of cotton and vegetables in India, is predicted with global climate warming [37, 66]. The 1–3°C rise in temperature will result in expansion of the European corn borer (*Ostrinia nubilalis* Hubner) distribution up to 1,220 km northward [26]. Continuous rainfall and heavy rainfall will be deleterious to Lepidoptera populations. It can depress flight and result in reduced mating and oviposition. The heavy downpour and cloudiness will result in drowning of larvae, the occurrence of epizoonotics in lepidopterous larvae [82]. Migration refers to the transfer of population from place to place by mass flights [83]. Dispersal is more simply defined as a movement that increases the mean distance between individuals. The intensity of *H. armigera* migration arrival in Central Europe is probably affected by the abundance of the species in its permanent range (north of Africa, the Mediterranean) and perhaps even by the actual weather situation in those regions, less so or not at all by that in Central Europe. Yet in warm and dry weather, these species may migrate farther northward and attain higher abundance in the subsequent generation(s), thereby increasing their noxious effects.

Increase in temperatures is directly relative to the number of insect migrant if the global warming continued as predicted in the twenty-first century; Britain and other northern temperate countries will receive larger numbers of migrant Lepidoptera. The temperature with wind and rainfall influences the takeoff of diurnal insects [84].

Climate warming within Europe will increase the numbers of migratory Lepidoptera reaching the UK. In years with warm summers, *H. armigera* will arrive from Portugal and Spain to the UK. Migrant individuals of *H. armigera* were observed in Denmark, Norway, Sweden [85, 86], Estonia, Latvia, Slovenia, Czech Republic, Poland (European Commission, 2006), and the Netherlands. During the summer, the range of *H. armigera* in Europe may extend as far as 59°N in the northern hemisphere.

5.7 *Impact of Climate Change on Insect Management Strategies*

Climate changes were effective integrated pest management such as cultural practices like crop rotation, early/late planting, pesticides, and natural enemies. Insects of short generation time have higher rates of increase and develop resistance to insecticides more quickly than insects of comparatively longer generation time. They will be less or not efficient with changing climate because of shrinking of crop growing seasons, colonization of crops by early insect arrival, and increased winter survival [36, 37, 51, 64]. The organophosphorus insecticides chlorpyrifos, leptophos, and phosfolan and the carbamate methomyl were found to be more toxic to larvae of a susceptible strain of *S. littoralis* when the temperature was increased from 20 to 35°C. But, the pyrethroids permethrin, fenvalerate, deltamethrin, cypermethrin, and flucythrinate were more toxic at 20°C than at 35°C. Resistance levels were reduced at low temperature [87].

Disruption of synchrony between insect pests and their natural enemies may upset the natural biological control [51]. Certain pesticides like pyrethroids, organophosphates, and especially the biopesticides being highly thermo-unstable degrade faster at higher temperatures. Altered temperature regimes may render many of these products to be less or not effective in pest control, necessitating frequent insecticide applications for effective control. This may intensify the pest problems due to the increased chances of resistance development in insects. Ultimately it will add to the increased cost of crop protection to the farmers and in turn environmental cost [51, 64, 88]. The forewarning models for predicting insect arrival/infestations based on earlier climate profiles need to be revised in accordance with location-specific changes in climate in order to provide a precise and accurate forecast of the pest incidence.

6 Climate Change and Insect Host Interaction

Insect–host plant interactions will change in response to the effects of CO_2 and temperature on nutritional quality and secondary metabolites produced by the host plants. Increased levels of CO_2 will enhance plant growth but may also increase the damage caused by some phytophagous insects [89]. In the enriched CO_2 atmosphere expected in the next century, many species of herbivorous insects will confront less nutritious host plants that may induce both lengthened larval developmental times and greater mortality [90]. The effects of increased atmospheric CO_2 on herbivory are not only species-specific but also specific to each insect-plant system. Although increased CO_2 tends to enhance plant growth rates, the larger effects of drought stress will probably result in slower plant growth. In atmospheres experimentally enriched with CO_2, the nutritional quality of leaves declined substantially due to dilution of nitrogen by 10–30% [91]. Increased CO_2 may also cause a slight decrease in nitrogen-based defenses (e.g., alkaloids) and a slight increase in carbon-based defenses (e.g., tannins). Acidification of water bodies by carbonic acid (due to high CO_2) will also affect the floral and faunal diversity [92]. Lower foliar nitrogen content due to CO_2 causes an increase in food consumption by the herbivores up to 40%, while unusually severe drought increases the damage by insect species such as spotted stem borer, *Chilo partellus* (Swinhoe), in sorghum [37].

7 Conclusions

Insects evolved 500 million years before, and still, now the process of coevolution of insects with the host and abiotic factors is going on. The rapid climate change also influences the insect evolution and makes its adaptation to climate change an indispensable thing in its evolution as the insect migration largely depends on the abiotic factors such as temperature, relative humidity, wind current, and direction, and a slight change in these parameters will alter their migration pattern to a greater extent. Technologies like monitoring insect pest migration with GIS, forecasting pest outbreaks, and modeling will help us to cope up with the changes in insect migration aggravated due to climate change. The insect migration in the pretext of climate change will result in the arrival of new insect pest to a new geographical region or earlier onset of existing insect incidence in a country. Thus the insect migration needs to be studied extensively in the changing climate scenario.

8 Recommendations

This chapter highlights the following recommendations for future considerations by researchers and interested stakeholders:

1. Impact of climate change on insect population dynamics, migration, and their natural enemies.
2. Breeding crops varieties that are more resistant to heat stress and insect pests.
3. Adjust sowing dates to prevent insect pest's outbreak.
4. Support and advise farmers on how to use integrated pest management more efficiently.

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Integrated Pest Management for Sustainable Agriculture

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Abstract Widespread insecticide resistance has been a major problem in a sustainable agriculture such as the resistance of *Tuta absoluta* (Meyrick) in tomato crops to some insecticides. Also, the increasing public concern over pesticide safety and possible damage to the environment has resulted in increasing attention being given to safety products for the control of agricultural pests. Integrated pest management (IPM) has become one of the major restricting factors for protected crop and vegetable cultivations in Egypt. The protections of human health, environment, ecosystems, and biodiversity have recently been considered as important elements in the application of agricultural practices. Integrated Pest management is carried out in a sustainable manner by combination of biological, cultural, mechanical, physical and chemical tools in a way that minimizes economic, health and environmental risks.

Despite the importance of the biological control in IPM, the basic principles of IPM are scouting and thresholds. If scouting and thresholds were the only IPM methods practiced by a grower, pesticide-use could usually be reduced by 50% compared to spraying on a regular schedule. Advantages of the use of pest-resistant varieties include low cost, increased security to the grower, decreased use of insecticides, the potential to enhance biological control through conservation of natural Enemies, easy transferability to farmers' fields, no danger to humans and domestic animals, and compatibility with all other control practices. Several new classes of insecticides became available and been registered in various crops. These compounds are highly efficient and very selective.

Keywords Agriculture, Biological, Integrated pest management, Pesticides, Sustainable

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1 Introduction

Widespread insecticide resistance has been a major problem in a sustainable agriculture. Resistance of *Tuta absoluta* in tomato crops to some insecticides has been reported in several countries, for example to abamectin, cartap and permethrin in Brazil [1]. Also, increasing public concern over pesticide safety and possible damage to the environment have resulted in increasing attention being given to safety products for the control of agricultural pests [2]. Egypt is the most populous country in the Arab world and the second most populous in Africa after Nigeria in population size. Egyptians live along the Nile and on the Mediterranean coast on 3 million ha because other parts of the country are covered by Sahara and Libyan deserts and this area must feed 90 million citizens. Modest calculations indicate that by 2018 the country's population may exceed 100 million [3].

In the USA, approximately 500 million kg (0.5 million metric tons) of more than 600 different pesticide types are applied annually at the cost of $10 billion [4]. Egypt consumed about 10,600 metric ton of pesticides (Active ingredient) during 2016 which represent 0.2% of the global consumption (5 million metric tons of a value of 52 billion dollars. In addition, 4 million metric tons (t) of chemicals and chemical products are annually imported into Egypt. These imported chemicals represent about 95% of manufactured chemicals found and used in the country [5].

A number of registered pesticides based on trade name reached 1,187 at 2016 compared with 566 at 2012. Based on the common name, it reached 264 at 2016 compared with 199 at 2012 [6]. Despite the widespread application of pesticides in the United States at recommended dosages, pests (insects, plant pathogens, and weeds) destroy 37% of all potential crops [7]. Insects destroy 13%, plant pathogens 12%, and weeds 12%. In general, each dollar invested in pesticide control returns about $4 in protected crops [7]. Even more than tenfold increasing in insecticide (organochlorines, organophosphates, and carbamates) use in the United States from 1945 to 2000, total crop losses from insect damage have nearly doubled from 7 to 13% [7]. The major economic and environmental losses due to the application of pesticides in the USA were: public health ($1.1 billion year); pesticide resistance in pests ($1.5 billion); crop losses caused by pesticides ($1.4 billion); bird losses due to pesticides ($2.2 billion); and groundwater contamination ($2.0 billion) [7].

Pest management has become one of the major restricting factors for protected crop and vegetable cultivations in Egypt. The protection of human health, the environment, ecosystems, and biodiversity have recently been considered as important elements in the application of agricultural practices. Hence, it is vital that the agro-ecosystem and sustainable systems in agriculture be considered when deciding pest control methods. More than ever the integration of multiple pest management tactics are needed for the development and implementation of sustainable IPM programs. This can be achieved primarily by employing cultural methods in harmony with other alternatives to pesticides. Also, using bio-pesticides and Host-plant resistance have always been key elements in transgenic techniques and IPM programs for agro-ecosystem. Also, biological control is also an important part of the agro-ecosystem. Behavior-modifying chemicals, as well as non-behavior-modifying pesticides, have also played important roles in IPM. Also, we must never forget that humans are an integral part of the agro-ecosystem, and it can be argued that the 'consumer' is a powerful, driving force in determining the composition of IPM programs.

2 Integrated Pest Management

Several definitions for Integrated Pest Management (IPM) were displayed, however all of them include the manage pests by reducing pest numbers to acceptable levels, taking into consideration protecting the environment, non-target organisms, and human health.

The IPM is "A pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in a compatible manner as possible, and maintains the pest populations at levels below those causing economically unacceptable damage or loss" [8]. Based on this concept, "IPM is a sustainable approach to managing pests that combines biological, cultural, mechanical, physical and chemical tools in a way that minimizes economic, health and environmental risks [9]. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms" [10]. There are four approacjes of thought promoting different options in IPM: one promoting the "dominant paradigm" integrated pesticide management, This can be achived by (1) training farmers on the right use of pesticides, (2) to target specific pesticides to minimize selection for resistance, (3) conserve beneficials and (4) reduce health and pollution risks [11, 12]. The second paradigm is IPM incorporating ecologically sound pest management tactics so that pesticides are essentially a last resort [13]. The third paradigm promotes a pesticide-free pest management [14]. The fourth paradigm is using transgenic crops to reduce pesticide (insecticide) use [15].

In Turkey, alternative applications to chemical control such as mechanical and physical measures, biological control, biotechnical methods and the use of resistant and/or tolerant varieties were specified in the guidelines [16]. "The IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms" [17]. Furthermore, specific pesticides have to be suggested to minimize adverse effects on natural enemies, humans and the environment when chemical control is a must [17]. Also, the pesticides containing high residual risk factors were excluded in the technical guidelines of IPM [16]. Also, the application of IPM could reduce control expenses, which in turn could compensate economic losses [18].

3 Compatibility of Management Strategies in IPM

IPM involves integration of cultural, physical, biological and chemical pest management techniques such as sanitation, exclusion, scouting, intervention, using compatible pesticides, accurate pest identification, and record keeping. In spite of the importane of the biological control in IPM, the basic principles of IPM are scouting and thresholds. Scouting is simply inspecting the crop (weekly) for the presence of pests. While, thresholds are simply deciding whether pests are abundant enough to require a control treatment. If scouting and thresholds were the only IPM methods practiced by a grower, pesticide use could usually be reduced by 50% compared to spraying on a regular schedule. The Ministry of Agricultural (Egypt) has taken several measures to reduce pesticide application and to limit its hazardous effects on the environment. Among these actions, implemented under the IPM programme, are: (1) Application of less-toxic pesticides. (2) Use of natural products as pesticides agents, releasing predators to eat rodents and insects in cultivated areas. (3) Seeking suitable cultural methods and balanced fertilizer use to help decrease pest populations. (4) Introducing genetic engineering technology to increase plant resistance to pests. (5) Improving sprayer techniques. Use of non-toxic bioregulators to increase plant resistance to pests. (6) Use of genetic manipulation messenger chemicals such as sex attractants and establishment of database systems in pest control programmes [19].

The largest successful and advanced IPM is the SPHINX Project. The project is a cooperative effort initiated in 1990 by the Egyptian MOA and Ciba-Geigy company. The aim of the project was to establish an IPM database and reporting system for Egyptian cotton. IPM was applied in Fayoum Districts during 1989–1990 due to the spreading of TYLCV. The programme is based on the following aspects: (1) Production of tomato seeding free from virus. (2) Protecting plants in permanent fields from infection by reducing the whitefly population. (3) Cultivating the productive cultivators under high infection conditions to examine productivity and their resistant levels against TYLCV. (4) Elimination of the natural sources of protection with TYLCV. (5) Establishing an integrated management programme for other diseases and bees that attack tomato crops [19]. Great efforts were made to integrate selective control methods of apple and pear trees in the Delta and Noubaria Districts to reduce the added chemical pesticides application. Control methods were achieved success against the clear-wing moth, the pubescent rose chatter, and the leopard moth and hibernated eggs of the European red mite [19]. The IPM production package was agronomically superior to farmers' traditional practices as it resulted in a higher yield in all locations. The average faba bean yield overall locations was 60.6% over that of farmers' practices. The IPM production package increased average wheat grain yield by 11.2% over that of farmers' practices [20]. The World Vegetable Center has recently developed, validated and promoted an IPM strategy for the control of eggplant fruit and shoot borer (EFSB) in South Asia during 2000–2005 [21]. The IPM strategy is composed of healthy seedling production, use of resistant cultivars and EFSB sex pheromone to continuously trap the adult males, prompt destruction of pest damaged eggplant shoots and fruits at regular intervals, and withhold pesticide use to allow the proliferation of local natural enemies to encourage the pest suppression.

4 Principle IPM

4.1 Scouting and Monitoring for Pests

Routine crop monitoring is the first and most fundamental step in adopting IPM. It is important to keep a check on the number of insects (both pest and beneficial) in your crop and to evaluate crop health [22]. The primary aims of monitoring are to detect and identify insect, mite and disease problems, and to observe changes in the seriousness of infestation. These are achieved by random plant inspections throughout the production area and by the use of sticky traps and indicator plants. Scouting each field every seven is recommended [22]. A basic strategy involves visual monitoring the same number of plants on a regular basis (e.g. 40 seedlings or 20 mature plants). It is recommended that monitoring sites are widely dispersed throughout the planting, including near crop boundaries. Monitoring should be carried out on at least a weekly basis – at critical points in crop development or pest outbreak situations, crops should be monitored more frequently [22]. Other monitoring tools include vacuum samplers, pheromone traps, light traps, coloured sticky traps, pitfall traps, visually inspecting plants, among others [23]. The trap capture data serves several purposes: ecological studies [24], tracking insect migration [25], timing of pest arrivals into agro ecosystems [26], initiating field scouting and sampling procedures; timing of pesticide applications [27], starting date or biofix for phenology models [28], and prediction of later generations based on size of earlier generations [29].

4.2 Pheromones

Sex pheromones are chemical signals that released by an organism to attract an individual of the same species of the opposite sex for mating [30]. The application of pheromones can complement existing management programmes [31], leading to a reduction in the use of broad-spectrum insecticides. Currently, pheromones and other semiochemicals are being used to observe and control pests in millions of hectares of land [32]. Sex pheromones have been widely used to monitor, forecast or play a more direct role in population suppression of moth pests [33]. The most widespread and successful applications of sex pheromones concern their use in detection and population monitoring [32]. They are also used to control insect populations, which is achieved by two main techniques: mass annihilation and mating disruption [32]. Pheromones are subdivided into several types such as sex pheromones, alarm pheromones and Aggregation Pheromones [34]. Pheromone traps are the most effective and sensitive enough to detect low-density populations. Pheromones are available for monitoring of American bollworm, spotted bollworms, pink bollworm, and *Spodoptera* in cotton. Install pheromone traps at a distance of 50 m per five traps per hectare for each insect pest [35]. Additional alternative control methods, based on the use of the insect's sex pheromones (lures), have been developed to control *T. absoluta* [36].

4.3 Light Traps

Light traps have been used for monitoring insect populations with a view to providing early warning of the population of pests, as well as for many other uses. Light traps have been widely exploited for monitoring the population dynamics of Lepidoptera and Coleoptera [37].

4.4 Sticky Traps

There have been a great number of researches on the strength of visual sticky traps against some pests [22, 38–40]. Sticky traps are also a useful tool for estimating thrips, whitefly, and other small flying species. In areas where tomato spotted wilt virus is common, sticky traps are orderly used to monitor levels of Western Flower Thrips (WFT) [22]. The yellow color attracts some insect species like moths, aphids, flea beetles, and whitefly. The trap is especially suitable to monitor the adult population density (Fig. 1c). Yellow sticky traps were reported to be effective on whitefly and aphid [42], blue sticky traps on thrips [38]. In placing the visual sticky pest traps to 10–15 cm over the plants by 1 for each 50–100 m^2 for monitoring the pests in the protected production, right after the time of transplanting seedlings are

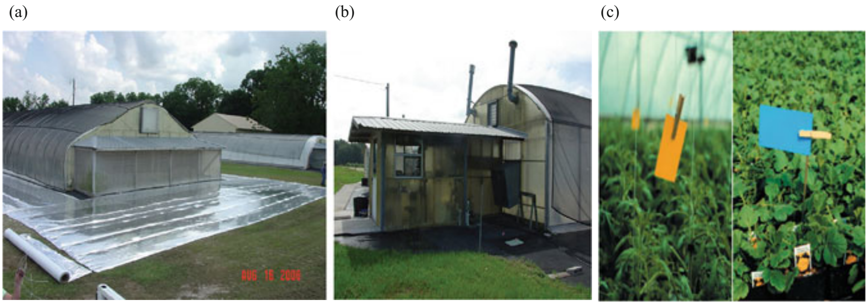

Fig. 1 Clear IPM techniques by exclusion of pests. (**a**) Metalized mulch application for greenhouse [41]. (**b**) Greenhouse air-lock entrance [41]. (**c**) Yellow sticky traps and blue sticky traps [23]

recommended. Following the determination of the first adult flight, 1 trap for each 10 m^2 is appropriate for mass trapping [16, 18].

4.5 Thresholds

Crop monitoring information, past crop records and any pest 'economic threshold' will help with deciding whether the pest numbers warrant active intervention. An 'action threshold' is the point at which you decide to act such as by putting on a pesticide [22]. Economic threshold (ET) is the number of pest whose injury to the plants cause a crop loss in dollars greater than the amount of money managing the pest would cost. The ET usually expressed in a number of pest individuals per some units (e.g., pest per square foot, per plant, per feet of row). Historical records, if available and accurate, can be used to help look at trends annually and seasonally. This would be a good resource to use when creating thresholds [43].

5 IPM Techniques

5.1 Physical Control

Physical control is measure that taken to remove or exclude pests from the collection environment. Physical control can be broken down into two areas: removal and exclusion.

5.1.1 Removal of Pests

Remove pests by using of insect traps, removing diseased or infested items or plants.

5.1.2 Exclusion of Pests

Sanitation

Sanitation is an important technique for any pest management program in preventing or reducing insect damage by removing breeding and hibernating sites. Therefore, the infested shoots, fruits and fallen leaves should be removed then destroyed or burnt. This helps reduce populations considerably [44]. It is important to keep the area outside the greenhouse free of weeds and other plants that could harbor pests. Greenhouse can be kept clean by using a ground cover or nursery cloth in at least a 10–20 ft. wide barrier adjacent to the greenhouse. If any weeds grow in that barrier area, they should be destroyed. In addition, maintaining a pure grass area after the nursery cloth barrier as far as practical is suggested. In field experiments, over a four-year period, cellulose sheeting prevented most weeds from emerging [45]. Shredding fallen leaves of apple in autumn, combined with 5% urea treatments (which accelerate decomposition of the leaves), reduced ascospore production by 92% [46]. Plant surfaces are coated with a fine layer of kaolin particles (aluminum silicate hydroxide) which disrupt arthropod recognition of plant surfaces [47], resulting in reduced oviposition and feeding. A wide range of insects have been shown to be affected, including psyllids and rust mites [47], aphids, spider mites and leafhoppers [48]; various Lepidoptera [49] and beetles [50]. In addition to the disruption of arthropod pests, some fungal pathogens are killed and heat stress is reduced in trees [50]. Remove plants that present a high risk due to attracting and harboring pests. In fact, proper disposal of waste and plant debris is one of the most effective ways of controlling many insects. Clean clothing, footwear and equipment as well as gloves, disposable coveralls and "booties" and footbaths, all help to reduce the risk of spreading pests and diseases. Complete jobs in younger, pest free plantings before going into older crops. Do not move from an infested greenhouse to a clean crop. However, sanitation must be used in conjunction with alternative management strategies including insecticides or natural enemies to minimize problems with plant-feeding insects in greenhouses. All benches should be sanitized before new plants are brought into your greenhouse.

Resistant Cultivars

Insect-resistant crops have been one of the major successes of applying plant genetic engineering technology to agriculture. The number of pest-resistant cultivars in different crops has greatly increased in recent years. Insect-resistant cultivars have been successfully developed and used in numerous field crops including rice, wheat, sorghum, and soybeans. These cultivars can be used alone or in combination with other control measures in an IPM program. Advantages of the use of pest-resistant varieties include low cost, increased security to the grower, decreased use of insecticides, the potential to enhance biological control through conservation of natural Enemies, easy transferability to farmers' fields, no danger to humans and domestic animals, and compatibility with all other control practices.

In addition to the problem of cultivar will not only solve a specific pest but will also be accepted by consumers in the market. However, like any technology directed toward insect management, there is the risk that insects will evolve methods of overcoming the plant's defenses.

So far, Bt-maize and Bt-cotton are the only insect-resistant *genetically modified crops* (GM crops) for commercial planting [51, 52]. The use of notable *Bt* crops, such as *Bt*-maize and *Bt*-cotton resistant to lepidopteran pests, have resulted in significant reductions of pesticide usage and clear benefits on the environment and farmer health. Consequently, *Bt*-crops can be a useful component of integrated pest management (IPM) systems to protect the crop from targeted pests and lower production costs [52–55]. This has led to a decline in chemical pesticide use of 443 million kg and an additional financial gain for farmers of US $78 billion in the last 15 years [56]. Since the commercialization of biotech crops in 1996, farmers have adopted the technology at such a dramatic rate that year 2012 witnessed the planting of 170.3 million ha of biotech crops by 17.3 million farmers in 28 countries around the world [56]. The USA and Canada are the only two countries to grow triple-stack maize with one gene for the European corn borer, a second for rootworm, and a third for herbicide tolerance [57].

Insect Screening

Modern technology in manufacturing has developed the capability to produce screening material so fine insects can be excluded from the greenhouse [58]. Insect screens with a fine mesh that excludes insects from the greenhouse especially whitefly winged aphid and jassids can be an important addition to an IPM program (Fig. 1b). Screens can be used effectively in both passively ventilated and fan and pad greenhouses.

Reflective or Metalized Mulches

Highly reflective or metalized plastic mulches have been used in agriculture for many purposes, but principally for the insects repelling, by covering the narrow raised beds in full-bed polyethylene mulch production system around the outside of the greenhouses with wide strips of the metalized mulch (Fig. 1a). The combination of screening and metalized mulch should be used together and will provide the greatest total reduction of whitefly entry [41]. Reflective mulch proved effective against winged aphid, whiteflies, thrips and leafhoppers, apparently because reflected ultraviolet light interferes with the insect's ability to navigate [59]. Numerous studies have shown that thrips are repelled and the incidence of TSW is reduced by metalized mulches [60–63].

5.2 Cultural Practices in IPM

Important yield damages occur when cultural practices are negligent in pest control.

IPM is knowledge-based and relies on local experience; this information will improve your ability to use IPM effectively in subsequent seasons.

Studies on IPM applications to farmers mainly focus on several cultural practices [16, 64]:

1. Resistance varieties to diseases or insect pests.
2. Use certified seed.
3. Planting materials should be healthy (pathogen-free) and certified.
4. In greenhouses air ventilation should be optimized to prevent raising relative humidity and temperature.
5. Prevent water accumulation around roots and if possible drip irrigation should be preferred.
6. Excessive nitrogen application must be prevented.
7. In poor and porous soil organic matter, compost or farm manure should be applied.
8. Weeds should be removed within and around cropping areas at regular intervals.
9. Before the activities in greenhouses.
10. Hands should be washed with soap and water.
11. Smoking should be avoided and after harvest crop rotation should be utilized.
12. Plant debris should be removed from the growing areas and others [65].

5.3 Biological Control

Natural enemies of insects, such as predators and parasitoids, have been recognized and employed for crop pest management for centuries. Although the studies initiated earlier in order to investigate the possibilities of biological control measures against vegetable pests such as *Macrolophus caliginosus* and *Encarsia formosa* against whiteflies [66], *Phytoseiulus persimilis* against *T. cinnabarinus* [67, 68] and *Diglyphus isaea* against leaf miners [69, 70], *Orius laevigatus* against *F. occidentalis* [71], they were actually started at the beginning of 2000s. In the early stages of biological control, it was only applied for pepper cultivation. *Eretmocerus mundus* and *Amblyseius swirskii* against whiteflies, *O. laevigatus* and *A. swirskii* against thrips, *Aphidius colemani* against aphids and *P. persimilis* against Carmine spider mite were successfully used as the biological control agents against the major pests of the pepper cultivation [17]. In India, *Phytoseiulus persimilis* mite has proved to be effective against spider mite in okra. Also in many European countries and in the USA, this predatory mite can be bought from specialized shops for release in greenhouses or in the field. Results in greenhouses experiments are very good and hardly for any chemical pesticides need to be applied for spider mite control. *Phytoseiulus* needs high humidity for effective mite control. The predatory mite *Amblyseius tetranychivorus*, indigenous in India, was also found effective against spider mite in okra. This predatory mite is commercially available in some western countries. It is released on fairly large scale for spider mite control in many vegetable crops including eggplant, strawberry, and gourds in China. Numerous research findings are available on how to mass-produce and conserve predatory mites. *Phytoseilus macropilis* has proved to be effective against spider mite under greenhouse in several countries, especially Egypt on the Strawberry, Cucumber and Cantaloupe [72]. *Trichogramma* species are relatively easy to culture and, being egg parasitoids, they kill the host before crop damage occurs, and commonly used groups of natural enemies [73, 74]. Observed rapid dispersal of *T. ostriniae* over distances of 35–230 m after an inoculative release of ~1 million wasps from a central release point. During a Farmers' Field School in Negros Occidental (1998/1999) in the Philippines, release of *Trichogramma chilonis* at a rate of 10–20 cards (containing the parasitoid) per hectare at 5-day intervals, depending on the infestation, resulted in 60% control of fruit and shoot borer (*FSB*). The first application was done 2 weeks after transplanting [18]. When *Trichogramma chilonis* was released at fortnightly intervals in a study in Tamil Nadu, India, it significantly reduced pest damage and produced fruit yield 20.30 tons, compared with the control yield of 13.06 tons [75]. Also, *Trichogramma japonicum* was released in eggplant fields in a study in Andhra Pradesh, India, and resulted very good control of shoot and fruit borer as compared to control [44]. Four indigenous species of *Trichogramma* spp. (*T. cacoeciae* Marchal, *T. cordubensis* Vargas and Cabello, *T. euproctidis* Girault and *T. bourarachae* Pintureau and Babault) Were obtained from field collections, done in two olive orchards from early spring to late summer (and occasionally fall) of the years 2002, 2003 and 2004 [76], and were identified using morphological and molecular methods. The dispersal and the relative progeny production of three indigenous (*T. bourarachae*, *T. cordubensis*, and *T. euproctidis*) and one commercially available (*T. evanescens*) parasitoid species were determined by monitoring parasitism on sentinel eggs placed on the release tree as well as on neighboring trees [77]. Whitefly has been considered to be the main pest in biological control applications on tomato, after several years of biological control implementations on peppers. Biological control of the whiteflies was done by combining of three agents; *M. caliginosus*, *E. formosa* and *E. mundus.* After the introduction of *T. absoluta*, the aspect on biological control was revised since it became the major pest of tomato production in several countries, especially Egypt. The new approaches on biological control of tomato pests were employed using *Nesidiocoris tenuis* feeding with both pre-adult period of whitefly and eggs and larvae of *T. absoluta* in system. The studies related to assessing alternative and native biocontrol agents against *T. absoluta* were also carried out [78]. Additionally, *E. mundus* is also being used for controlling whiteflies [18]. *D. isaea* has been released in greenhouses for controlling leafminers [69, 70]. Mostly, the pests are easily controlled by the naturally occurrence of parasitoid species such as *D. isaea*, *D. crassinervis*, *Neo-chrysocharis formosa*, *Chrysonotomyia chlorogaster*, *Hemiptarsenus* sp., etc. in the IPM conducted greenhouses [70, 79]. Predators such as ladybeetles and hoverflies (*Syrphids*) and parasitoids like the wasp *Diaeretiella rapae* and *Aphidius* sp. are important natural enemies of the aphid.

5.4 Biopesticides

Biopesticides, biological pesticides, biocontrol agents, or microbials, are pesticides that contain a living organism as active ingredient.

Among the botanical pesticides, neem (*Azadirachta indica*) is being widely used and several formulations thus containing the active component azadirachtin are commercially available out [80]. The seed of eggplant can be protected from some soil-borne fungi and from cutworms by a coating of a botanical extract such as crushed garlic (crushed to obtain juice and pulp). Seed is mixed with this extract. Garlic is well known for its strong odor which has a repellent effect on insects, or birds, and it can prevent diseases. In Vietnam, vegetable farmers have utilized several botanical pesticides, including extracts from Derris roots, tobacco leaves and seeds of Milletia, which they claim to be effective. However, in addition to pest insects, some natural enemies may be killed by botanicals. Studies in cabbage fields in Kenya showed that chili sprays reduced pest numbers by 50% in the first week after application, but these build up again, so farmers concluded from this experiment that chili needs to be sprayed every 14 days for effective control out [81]. The area of land under transgenics or GM crops is continuing to increase throughout the world. However, production of most of the dominant crops such as soybean, maize, canola, and cotton remains concentrated in the USA, Canada, and Argentina, followed by Brazil, China, Paraguay, India, and South Africa out [82]. Several reports have confirmed the effectiveness of entomopathogenic fungi against various pests on vegetables. Out [83] documented that isolates of *B. bassiana* and *M. anisopliae* caused 71–100% mortality of *Tetranychus urticae* between 25 and 35°C. Hence, temperature and humidity are important factors determining the effectiveness of entomopathogenic fungi. Additive effects were found on the mortality of diamondback moth when entomopathogenic fungi were combined with the parasitoid, *Oomyzus sokolowskii* out [84]. However, the parasitism was reduced when the diamondback moth was treated with entomopathogenic fungi 24 h before the exposure to the parasitoid. The entomopathogenic fungi caused 9–21% confirmed mortality of the parasitoid and *S. litura* out [85].

5.5 Selective Pesticides

Several new classes of insecticides became available and been registered in various crops, including neonicotinoids, insect growth regulators (including chitin synthesis inhibitors and ecdysone agonists), anthranilic diamides, and spinosyns, among others. These compounds are highly efficient and very selective out [86]. Current insect pest management research and extension programs must be designed to address issues related to insecticide efficiency, environmental concerns, and production costs. In recent years, two highly selective acaricides have been developed for spider mite control. The compounds hexythiazox and clofentezine work only on eggs of Tetranychidae. These compounds are not toxic even to other mites outside the family Tetranychidae. This includes the predatory family Phytoseiidae, and rust mites (Eriophyidae). The insecticide spinosad is the first representative of this new class of pesticide chemistry. This product has two main components, spinosyns A and D. Spinosad is effective against a variety of lepidopterans, such as beet armyworm, *Spodoptera exigua* (Hubner) out [87].

5.6 Biotechnology and Host-Plant Resistance

The relationship between the insect and plant depends on three kinds of resistance, e.g. antibiosis (affects the biology of the insect-pest to reduce its abundance) lead to increase mortality or reduce longevity and reproduction of the insect. While antixenosis (affects the behavior of an insect-pest) lead to as non-preference of the insect for a resistant plant. Tolerance is resistance in which a plant can withstand or recover from damage caused by insect-pest abundance. Using genetic engineering and plant biotechnology, the gene-part that encoded the activated Bt toxin could efficiently be transferred from *B. thuringiensis* cells to plants. Tobacco was the first plant in which the *Cry* gene was first found to be expressed. However, such plants produced the active toxin protein to a level that was insufficient to cause effective mortality in the target insect pest. This low-level expression of these genes in eukaryotic systems could be attributed to a number of factors, the first of these being the relatively higher A + T content of prokaryotic (*Bacillus*) DNA than in eukaryotic plants. In general, plants have an overall preference for G + C content in the 3rd codon position out [88] as against A + T in the case of prokaryotic organisms in this degenerate base. Modification of the 3rd codon position from A or T to G or C, in the native *Cry* gene (through chemical synthesis of the gene), resulted in its increased expression in plants. Expression of this synthetic *Cry1Ac* endotoxin gene in transgenic plants showed a 1,000-fold increase to result in effective insect control out [89]. Similarly, other *Cry* genes have been modified and expressed in tobacco, rice, coffee and other plants to achieve enhanced insect control protein levels out [90–92]. Transgenic cotton that produced one or more insecticidal proteins of *Bacillus thuringiensis* (Bt) was planted on over 15 million hectares in 11 countries in 2009 and has contributed to a reduction of over 140 million kilograms of insecticide active ingredient between 1996 and 2008 [93]. Also, *B.t.* sweet corn performed better and required fewer sprays than conventional sweet corn to meet market standards, thus reducing hazards to farm workers and the environment out [94].

5.7 Advances in Pest Management

Several new trends were used in pest control such as Biotin-Binding Proteins (Avidin and Streptavidin). Avidin and streptavidin are insect growth-inhibiting proteins whose genes could potentially be expressed in tobacco plants expressing avidin, streptavidin to provide inbuilt plant resistance to larvae of *Spodoptera litura* and *Phthorimaea operculella*. The toxic effect of these proteins towards insect pests was established by growth retardation leading to effective mortality of these larvae out [95, 96]. Also, Chitinase enzymes produced by different microbial, plant and insect species catalyze the hydrolysis of chitin. Chitinase enzymes target chitin in the peritrophic membrane of the midgut causing a reduction in survival and growth out [97]. Proteinase Inhibitors interfere with the activity of midgut proteinases that help the insects in drawing their essential nutrients (peptides, amino acids) from feed proteins, thus causing nutritional limitations. Most significant among these are soybean trypsin inhibitor (SBTI), cowpea trypsin inhibitors (CpTI) and polyphenol oxidase. Expression of α-amylase inhibitor gene from *Phaseolus vulgaris* in seeds of transgenic garden pea (*Pisum sativum*) and other grain legumes caused this inhibitor protein to accumulate up to the 3% level. This could provide significant seed resistance to larvae of bruchid beetles and pea weevil *Bruchus pisorum* out [98]. Plant lectins represent a class of a heterogeneous group of proteins that specifically bind with sugars to cause sugar limitations out [99]. These glycoproteins constitute direct defense responses in plants against attack by phytophagous insects. Most lectins are multivalent and capable of agglutinating cells and hence are toxic to animal cells.

6 Applicability in Egypt

Cotton in Egypt is subject to loss in yield and quality by insects; especially oil contents in the seeds. The most important of these pests are *Spodoptera littoralis*, *Pectinophora gossypiella* and *Earias insulana* that cause crop loss from nearly 1 million ha cultivated annually in Egypt [100]. Chemical pesticides had great impact on cotton yield and therefore the emphasis in IPM in Egypt is on cotton. Amin and Gergis [100] describe an improvement in insect control practices directed against these insects, by integration of monitoring, biological control, cultural, behavioral and genetic aspects, and bio-insecticides that can serve as a basis for the formulation of a biologically-based new approach of integrated management of key cotton pest. Field studies were conducted in 150 ha of cotton (Giza-80) during 2004 and 2005 at Minia Governorate, Middle Egypt. Percentages of infestations, cotton yield and population density of both natural enemies and sucking pests were evaluated [100]. Also, in Egypt, mango (*Mangifera indica* L.) suffers from several diseases and insects at different stages of its life. Three foliar application of bio agents (i.e., *Streptomyces* sp., *Pseudomonas fluorescens*, *Bacillus brevis* and *Tilletiopsis minor*), natural compounds (i.e., ascorbic acid and methyl jasmonate) alone or in combination to mango trees markedly reduced infection with malformation, anthracnose, powdery mildew, dieback diseases, mites, insect in leaves, blossom clusters as well as increased fruit set and yield in Ewais and Seddek [101].

Tuta absoluta (Meyrick) *is* a new exotic pest in Egypt. It is one of the recent destructive pests attacking tomato crop in several countries. Based on the infestation reduction rate, release of the egg parasitoid, *Trichogrammatoidea bactrae* + mass trapping showed best results, followed by the application with Biotrine and Fytomax + mass trapping and lastly use of insecticides as control [78].

7 Conclusions

The principle objectives of IPM are to develop economically, socially and environmentally acceptable pest control tactics. The basic principles of IPM are scouting and thresholds which reduces the use of pesticides by 50%. Integrated Pest management is carried out in a sustainable manner by combination of biological, cultural, mechanical, physical and chemical tools in a way that minimizes economic, health and environmental risks.

8 Recommendations

We recommend that all farmers and exporters in the world, especially Egypt, carry out integrated pest control programs in the management of crops, vegetables and fruits to reduce economic cost and to minimize environmental and health risks.

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Organic and Biofertilization on Crop Production in Semiarid Regions

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Abstract Organic farming involves holistic production systems that avoid the use of synthetic fertilizers, pesticides, and genetically modified organisms, thereby minimizing their deleterious effect on the environment. Agriculture area under organic farming ranges from 0.03% in India to 11.3% in Austria. Organic agriculture is the system that favors the maximum use of organic matter and microbial fertilizers to improve soil health and increase yield. Organic agriculture has a long history, but it shows a recent and rapid rise. This article describes the importance of organic and biofertilizers in increasing the quality and productivity of developing crops under semiarid regions, especially in salt-stressed areas, and their role in improving the properties of these lands.

The organic farming system is largely dependent on the cycle of crops, crop residues, legumes, green fertilization, organic residues from outside and inside the farm to maintain soil productivity, and organic agriculture, as pest control, insect, animal, fungal or weed. The use of organic fertilizers, natural and manufactured instead of using chemical fertilizers, and the use of alternatives to pesticides and green pesticides are safe and have a good impact on agricultural products in terms of production of clean agricultural crops that are safe to human health and pollution-free.

In Egypt, the expansion of organic agriculture will be an added value in some areas of the project of reclamation of one and a half million acres, in addition to the state's interest in the expansion of agricultural plantations. Also, Egyptian organic agriculture has a comparative advantage in terms of production dates and quality of European market countries. The number of organic farming in the world is growing rapidly. In terms of numbers, the area cultivated by organic methods increased from 1.15 million hectares in the early 1970s to 11 million hectares in 1999 and reached 43.7 million hectares in 2014, which nearly quadrupled in 15 years. Egypt is ranked third after Tunisia and Uganda among African countries, where the area organically grown in Egypt according to global statistics to 85.8 thousand hectares in 2014.

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Biofertilizers are preparations containing microorganisms that can supply plants with the necessary nutrients from natural sources, thus reducing dependence on different chemical fertilizers. These fertilizers can release nutrients continuously, making them sufficient to cover the needs of the treated plants. Biofertilizers are also sources of food for low-cost plants as a substitute for the use of mineral fertilizers, which have the effect of polluting the environment, whether for soil or water, when excessively used. These fertilizers are produced from microorganisms by selecting the desired microbes to multiply in suitable farms and then transferring the bacterial growth to a suitable liquid or solid carrier and are used as a vaccine, where they are added to the agricultural soil either as mixed with soil or mixed with plant seeds when planting. Only those microorganisms are used which have specific functions to enhance plant growth and reproduction by increasing the efficiency of nutrients and increasing their availability in soil.

This chapter gives a quick picture of the important use of organic and biological fertilizers to increase the efficiency of the fertilizers of macroelements, especially the nitrogenous one, and the effect of this on the productivity and quality of barley grains growing under the conditions of semiarid regions, especially those suffering from salt stress.

Keywords Biofertilization, Crop production, Organic fertilization, Semiarid regions

Contents

1 Introduction

Solving the problem of shortage in food production to face the demand of the fast-growing population is a national goal for the Egyptian government. Therefore, increasing the productivity of crops, such as oil crops and cereals especially sunflower, wheat, and barley, became a necessity to minimize the gap between our total production and consumption. Many researchers paid great attention to increase the productivity of these crops per unit of cultivated area through mineral fertilization. Such a fertilization practice, although increasing grain yield, occurs at the expense of both soil health and environment. It is now unanimously agreed that decreasing fertilizer use efficiency (FUE) and declining soil organic matter (SOM) levels are serious threats to sustainability.

Barley (*Hordeum vulgare* L.) is one of the most important cereal crops in Egypt. The total production of barley in Egypt reached 108,000 MT in 2017, produced from an area of 83,000 ha, whereas the consumption amounted to 208,000 MT with 2.46% growth rate [1].

Organic agriculture is a production management system that promotes and enhances ecosystem health, including biological cycles and the biological activity of soil. It is based on minimizing the use of external inputs and represents a deliberate attempt to make the best use of local natural resources. Methods are selected to minimize pollution of air, soil, and water. Organic agriculture comprises a range of land, plant, and animal management procedures, circumscribed by a set of rules and limits that are usually enforced by inspection and certification schemes. Synthetic pesticides, mineral fertilizers, synthetic preservatives, pharmaceuticals, genetically modified organisms, and sewage sludge and irradiation are prohibited in all organic standards.

The land area under organic management has been steadily increasing worldwide for several decades, reaching 37.2 million ha in 2011, up from 11 million ha in 1999. The total value of organic food and beverages sold in 2011 was almost US$63 billion, some US$4 billion higher than in 2010. The organic market has grown considerably since 2002, and unlike the rest of the food sector, it has continued to grow, despite the global economic slowdown.

However, data show that organic agriculture is not widespread in the Near East and North Africa. In 2011, most countries had less than half of one percent of their agricultural area dedicated to organic agriculture, except for Tunisia (1.8%) and Egypt in which its organically certified area has increased to almost 80,000 ha, although still a very limited area comprising less than 2.5% of Egypt's cultivated land [2].

Organic farming is an agricultural system that aims to improve food security and preserve the environment in addition to attending to economic conditions and the requirements of the community. Also, it reduces the use of external additives, such as chemical fertilizers, pesticides, and hormones, and depends on the natural ability acquired in the resistance of diseases and pests [3, 4].

Organic fertilizers are environmentally friendly; they are an important source of hard currency and increase in national income. They are an attractive agriculture for labor, which allows for the continuous creation of new jobs and contributes to solving the unemployment problem. They will contribute to rural development and better absorption of labor and raise the incomes of small farmers. Also, they improve and maintain the natural status of the agricultural system by avoiding the depletion and pollution of natural resources. They provide an adequate economic return through healthy and safe working conditions. They improve biological courses in the farm, especially nutrient courses, to produce healthy food of high quality and in sufficient quantities [5].

They maintain the fertility of the soil and work to increase it in the long term and reduce all forms of pollution to a minimum. They reduce greenhouse gas emissions such as carbon dioxide, methane, and other gases, which lead to pollution of the environment, and reduce pollution of air, water, and soil with toxic and lethal pesticides to some insect or microbial species, leading to imbalances and subsequent disease and pests. The world witnessed a significant increase in the production and consumption of organic products for the consumer's concern about the use of safe food which does not adversely affect health by Chemicals, pesticides, or other chemicals related to production [6–12].

The combined use of organic manures and inorganic fertilizers influences the physical, chemical, and biological properties of the soil and plays an important role in energy flow and nutrient cycling. It does not only sustain higher levels of productivity but also improve soil health and enhance nutrient use efficiency [13]. If soil biodiversity is the guardian of soil fertility and the health of the soil and crops, then frequent additions of fresh organic matter are the guardians of soil biodiversity [14].

The adoption of management practices such as crop residue treatment, the use of catch crops, or the appropriate timing and amount of manure application determines the degree to which yields and nutrient losses are affected [15]. Residue harvest removes more nutrients from the agroecosystem than grain harvest alone [16]. After a long-term experiment [17], concluded that the incorporation of cereal straw as the only source of organic fertilization sustained wheat and barley yields near the production level of the system. Montemurro [18] indicated that the partial substitution of mineral N with organic N did not reduce yields and that N utilization and mixed fertilization resulted in a good balance between productive parameters, N utilization efficiency indices and soil N deficit, while also involving lower pollution risks. The combined application of chemical fertilizer and maize straw with a wide C/N ratio is an important way of reducing the superfluous accumulation of N fertilizer [19]. Organic fertilizers contain macronutrients, essential micronutrients, vitamins, growth-promoting indole acetic acid (IAA), gibberellic acid (GA), and beneficial microorganisms [20].

Extending the role of biofertilizers can reduce the need for chemical fertilizers, decrease adverse environmental effects, and fix atmospheric N2. Therefore, biofertilization is of great importance in alleviating environmental pollution [21, 22]. Inocula of *Azotobacter* sp. and *Azospirillum* sp. are used as biofertilizers for many crops. The estimated contribution of these free-living N-fixing prokaryotes to the N input of soil ranges from 0 to 60 kg/ha per year [23]. The existence of microbial communities like *Azotobacter* sp. and *Azospirillum* sp. in the rhizosphere promotes the growth of the plant through the cycling and availability of nutrients, increasing the health of roots during the growth stage by competing with root pathogens and increasing the absorption of nutrients and water (http://ijsrst.com/paper/1334.pdf) [24]. Kizilkaya et al. [25–27] studied the effects of *Azotobacter* sp. and *Azospirillum* sp. inoculation on wheat and found that the highest plant height, spike per unit of area, grains per spike, grain weight, and straw, grain, and biological yields were obtained when wheat plants were inoculated with these inoculants. Saini and Piccinin [28, 29] suggested that integrated nutrient management strategies involving inoculation of seeds with *Azotobacter* sp. and *Azospirillum* sp. in combination with chemical fertilizers result in improving both growth and yield of crops. Inocula of organisms which act as biofertilizers are prepared in different forms (in suspensions or on the solid organic matter) and are marketed commercially under different trade manes. In Egypt one of such products is Cerealin (produced by the Ministry of Agriculture, Egypt) which consists of inocula of N2-fixing strains of *Azospirillum lipoferum* and *Bacillus polmxa.* Another product is Microbin which consists of N2-fixing microorganisms along in the P-dissolving microorganisms [30].

Haque [31] stated that bio-inoculation of mustard and tomato plants with *Trichoderma* enriched with inorganic fertilizers plays a significant role in increasing their growth and yield and reduces 50% of the inorganic fertilizer cost.

PGPR, plant growth-promoting rhizobacteria, inoculants play an important role in reducing the quantities of chemical fertilizers used and contribute to improving soil fertility and reducing a negative environmental impact [32]. The classification of biofertilizers as [33] is shown in Fig. 1.

Nitrogen is an important nutrient in plant nutrition and is needed by plants in large quantities. It represents the largest amount of organic constituents of plants, including proteins, enzymes, nucleic acids and chlorophyll, cytochrome, and some vitamins. Thus, N supply to the plant will influence the amount of protein, cell size, leaf area, and photosynthetic activity [34]. N fertilizer causes a positive effect on the number of grains per spike, spike weight, 1,000 grain weight, and grain yield of wheat [35, 36]. Namvar [37] found that high rates of N fertilization and biofertilizer (*Azotobacter* sp. and *Azospirillum* sp.) inoculation increased number of grains per spike, 1,000 grain weight, grain yield, biological yield, and grain protein content of the wheat plant.

Soil salinity is one of the important factors affecting growth and yield of most crops. Many workers reported that application of organic manure and biofertilizer could alleviate the adverse effects of soil salinity on both soil and the grown plants. In this concern, Poraas et al. [38] stated that maize grain yield, 100 grain weight, and stover yield which grew on saline soil (EC dSm^{-1} in soil paste, 10.7) were significantly increased due to organic and bio-treatments. Omran [39] reported that the interaction effect between FYM with 50% of the recommended dose of N and biofertilizer inoculation induced a significant increase in growth parameters, seed quality, and chemical compositions of flax seeds grown on sandy soil [40] found that organic fertilizer sources (i.e., plant residues and FYM) greatly enhanced the grain yield and yield components of wheat grown on brown forest soil.

The present work aims at identifying the effective role of applied organic compost and bio-inoculation with *Rhizobium radiobacter* sp. strain (salt-tolerant PGPR) applied solely or in combination with chemical N fertilizer (urea) on maximizing the productivity of barley plants grown under saline-sodic soil condition. Evaluating

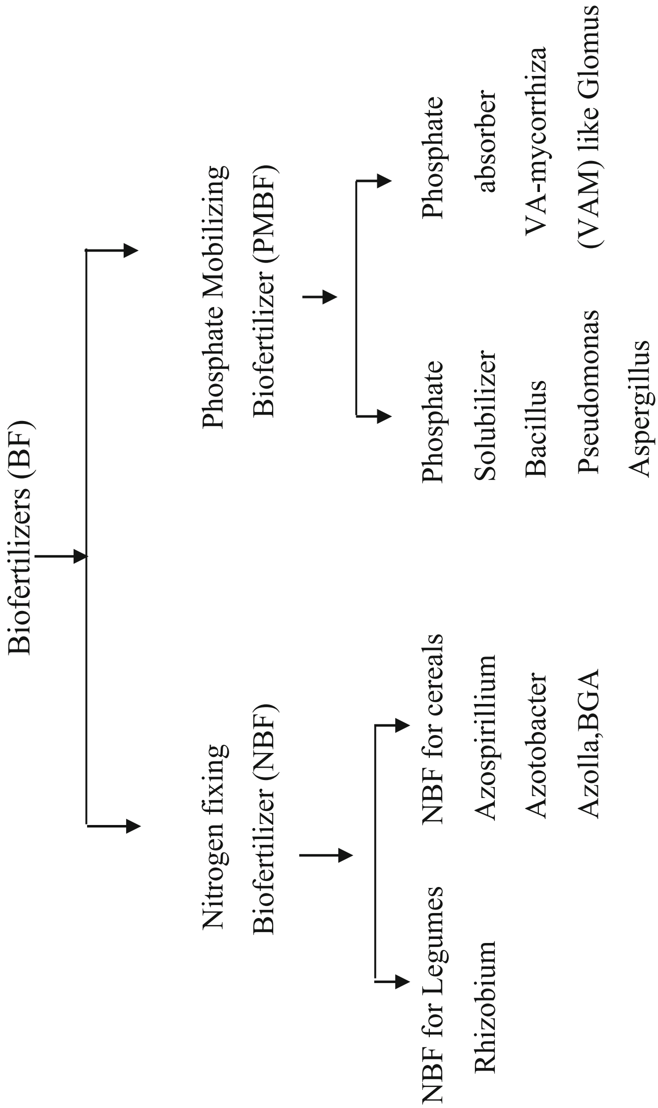

Fig. 1 Classification of biofertilizers

the optimal use of nitrogen fertilizer when combined with the abovementioned treatments on barley yield and its quality as well as its contents of some nutrients besides the implications of the used treatments on some soil properties were also taken into consideration in this study.

2 Description of Experiment

A field experiment was carried out on a saline-sodic sandy loam soil at Gelbana village, North Sinai Governorate, Egypt, during the two successive winter seasons of 2011/2012 and 2012/2013, using a randomized complete block design with three replicates. The purpose of this experiment was to evaluate the effect of biofertilizer (*Rhizobium radiobacter* strain, salt-tolerant PGPR), urea (460 g N kg^{-1}), and organic fertilizer (compost) on grain quality, productivity, and contents of some macro- (N, P, and K) and micronutrients (Fe, Mn, and Zn) of barley plants. Also, soil properties after harvest were taken into consideration. A representative soil sample of the field was taken from 0 to 30 cm layer and used for determining some physical and chemical properties as presented in Table 1.

The soil experimental field was pretreated by applying the gypsum requirements and then plowing the soil to a depth of 30 cm. Therefore, continuous leaching process was carried out through adding water over the surface of the soil at a distance of about 15 cm while maintaining this layer for at least 3 days. After 2 weeks of leaching process, laser technique was used for leveling the soil surface followed by deep subsoiling, plowing, and establishing field drains at a depth of 90 cm at the beginning of each drain followed by establishment of an irrigation canal in the middle part of the experimental area. The soil was irrigated from El-Salam Canal (a mixture of Nile water and agricultural drainage water) (Table 2).

Compost was prepared using 2 tons of air-dried straw residues (rice straw, maize stover, and faba bean straw), and its chemical composition is shown in Table 3.

Barley seeds (*Hordeum vulgare* cv. Giza 126) were inoculated with biofertilizer which was prepared from *Rhizobium radiobacter* sp. strain (salt-tolerant plant growth-promoting rhizobacteria, PGPR) isolated from the rhizosphere soil of Sahl El-Tina location and deposited in the gene bank under number of HQ395610 Egypt by Bio-fertilizer Production Unit, Department of Microbiology, Soils, Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt. *Rhizobia* inoculant was applied at a rate of 100 g of the inoculant for 15 kg seeds wetted with 300 mL of adhesive. The moist seeds were thoroughly mixed with the inoculants in the shade, sown immediately, and covered with soil in order to minimize *Rhizobia* exposure to the sun. Seeds of barley were sown, 20th and 25th of October 2011/2012 and 2012/2013, respectively. The inoculation of the *Rhizobia* strain was added three times at 21, 45, and 65 days after planting at a rate of 12 L of the inoculant suspension/950 L water ha^{-1}.

The treatments were arranged in a randomized complete block design with three replicates. The plot area was 40 m^2 (4 m width and 10 m length). Soil was amended

Table 1 Physical and chemical properties of the investigated soil

Property	Value
Particle size distribution (%)	
– Clay	16.76
– Silt	10.24
– Fine sand	68.31
– Coarse sand	4.69
– Textural class	Sandy loam
– EC (dSm^{-1}) in soil paste	15.3
– pH [soil suspension 1:2.5]	8.12
• Organic matter ($g\ kg^{-1}$)	4.81
• SAR	28.0
– Soluble ions ($mmol_c\ L^{-1}$)	
• Na^+	117
• K^+	0.80
• Ca^{++}	12.8
• Mg^{++}	22.2
• Cl^-	103
• HCO_3^-	10.6
• $SO_4^=$	39.2
• $CaCO_3$ ($g\ kg^{-1}$)	85.7
• ESP	28.6

Available macro- and micronutrients ($mg\ kg^{-1}$ soil)

N	P	K	Fe	Mn	Zn	Cu
30.0	3.25	195	5.96	2.26	0.83	0.02

Critical levels of nutrients in soil after [41]

Limits	N	P	K	Fe	Mn	Zn
Low	<40.0	<5.0	<85.0	<4.0	<2.0	<1.0
Medium	40–80	5–10	85–170	4–6	2–5	1–2
High	>80.0	>10.0	>170	>6.0	>5.0	>2.0

Table 2 Chemical properties of the irrigation water in the 2 successive years of study

Property		Season		
		2011/2012	2012/2013	Average
	pH	7.89	7.93	–
	EC (dSm^{-1})	1.46	1.32	1.39
Macronutrient ($mg\ kg^{-1}$)	$N-NH_4^+$	7.99	6.55	7.27
	$N-NO_3^-$	7.32	7.68	7.50
	P	2.08	2.14	2.11
	K	9.02	9.08	9.05
Micronutrient ($mg\ kg^{-1}$)	Fe	0.97	0.86	0.92
	Mn	1.32	1.35	1.34
	Zn	0.72	0.78	0.75

Table 3 Chemical properties of the compost used in the study

Property	pH (1:2.5)	EC dSm^{-1} (1:10)	O.C	C/N ratio	Total macronutrients ($g\ kg^{-1}$)			Total micronutrients ($mg\ kg^{-1}$)		
					N	P	K	Fe	Mn	Zn
Compost	7.95	4.60	35.7	23.6	15.1	6.61	18.6	699	431	286

with compost 20 days before sowing at a rate of 6 mega gram (Mg) ha^{-1} and ordinary superphosphate (67.6 g P kg^{-1}) at a rate of 31 kg P ha^{-1} during seedbed preparation. Also, all treatments received potassium fertilizer 60 kg K ha^{-1} as potassium sulfate (400 g K kg^{-1}) in two equal doses at 21 and 42 days after planting. All normal agricultural practices recommended for the region were applied. Nitrogen fertilizer was applied as urea, 460 g N kg^{-1} at three rates 0, 119, and 179 kg N ha^{-1} equivalent to 0, 50, and 75% from the recommended rate for barley in three equal doses, started before planting and then 30 and 50 days after planting.

2.1 The Experiment Treatments

The experimental treatments were as follows:

1. N0, control (non-treated)
2. N1, mineral N (119 kg N ha^{-1})
3. N2, mineral N (179 kg N ha^{-1})
4. Biofertilizer, (Bio), by inoculation with *Rhizobium radiobacter* strain (PGPR) as a salt-tolerant rhizobacteria
5. Bio + N1
6. Bio + N2
7. Compost (6 mega gram, Mg ha^{-1}), mega gram = 10^6 g = metric ton
8. Compost + N1
9. Compost + N2

Harvest was done on 27th of April and 2nd of May 2011/2012 and 2012/2013, respectively.

2.2 Plant Analysis

At harvest, ten plants were taken randomly from each plot and tagged for yield components. Grain weight per spike and 1,000 grain weight were measured. Total proline content was determined according to [42]. Also, plants in an area of 2 m^2 of each plot were harvested and air-dried, and then straw yield, grain yield, and biological yield were estimated. Representative ten plants were taken and the following parameters were calculated:

- Grain protein contents by multiplying grain N% by 5.83 [43].
- Grain protein yield in kg ha^{-1} {protein content g kg^{-1} × grain yield Mg ha^{-1}}.
- Harvest index (HI): (grain yield/biological yield) × 100.
- Yield efficiency: (grain yield/straw yield) × 100.
- Apparent N recovery (ANR) by the equation described by [44], i.e., ANR = [N uptake (fertilized plot) – N uptake (zero plot)/N fertilizer rate] × 100.
- Nitrogen agronomic efficiency (NAE) for N according to [45]: [grain yield (fertilized plot) – grain yield (zero plot)]/N fertilizer; yield and N fertilizer in kg ha^{-1}.
- Nitrogen use efficiency (NUE) is the N applied to produce yield and is defined here as the amount of grain yield per unit of applied N (kg of grain yield kg^{-1} of N applied) as described by [46].

Macro- and micronutrient contents of grain and straw samples were determined in aliquots of digested solutions resulting from the digestion of grain and straw samples by a mixture of H_2SO_4 and $HClO_4$ acids after drying in an oven at 70°C as described by [47].

2.3 Soil Characteristics

After harvest, representative soil samples of the field were taken (0–30 cm layer) from each plot. Samples were analyzed for EC (in soil-paste extract) and pH (in 1:2.5 soil/water suspension) according to [41]. Available nitrogen was extracted by KCl 2N extract and estimated by steam distillation procedure using MgO-Devarda's alloy according to Bremner and Keeney's method described by [48]. Available phosphorus was extracted using 0.5N Na HCO_3 solution at pH 8.5 and determined colorimetrically according to [49]. Available potassium was extracted using 1N ammonium acetate at pH 7.0 and determined photometrically according to [50]. Available iron, manganese, and zinc were extracted by DTPA and measured using atomic absorption spectrophotometer as described by [51].

2.4 Statistical Analysis

Data of the two seasons were subjected to statistical analysis of variance (ANOVA) and the least significant differences (LSD) at 5% level according to [52].

3 Results and Discussion

3.1 *Soil Chemical Properties After Barley Harvest*

3.1.1 Soil pH

Data in Table 4 show the effect of mineral, bio-, and organic N fertilization on some chemical properties of the soil at the end of the experiment. The values of pH were slightly decreased as affected by all the studied treatments for the two seasons. These results are in agreement with those of [53] who reported that the decrease in pH was marked particularly when N and compost fertilization were combined. The highest decrease in pH value was achieved by treating the soil by compost + N2. Such decreases in soil pH might be attributed to the effect of microorganisms on decomposing organic matter releasing organic acids and producing several phytohormones such as indole acetic acid and cytokinins. These results are similar to those obtained by [54, 55].

3.1.2 Total Soluble Salts

Data presented in Table 4 show that soluble salts decreased when the compost or biofertilizers were applied alone or in combination with N fertilizer. This would improve soil conditions for plant growth. Improvement in porosity and aggregation may have occurred due to the applied compost and biofertilizer and hence enhanced the leaching of salts [56]. The reclamation pretreatments executed before experimenting enhanced the positive effect of bio- and organic fertilization. Organic acids must have provided a substantial modification of soil physical properties, especially soil structure as well as soil aggregation and drainable pores. Consequently, these favorable conditions would positively affect soil permeability and encourage the downward movement of water carrying Na-salts out of the soil. These results are in agreement with those of [57, 58]. The lowest EC values (10.3 and 9.07 dSm^{-1}) were recorded with the treatment Bio + N1 at the first and second seasons, respectively. The used treatments could be arranged according to their effects on reducing EC of soil in the following descending order: biofertilizer treatment when added solely or in combination with N1 and N2 followed by compost treatment when added solely or in combination with N1 and N2 and then mineral N fertilization at the rates N1 and N2. This trend was found true for the two seasons. These results are in agreement with those obtained by [59] who found that besides the improvement in soil aggregation caused by compost, its decomposition when combined with biofertilizers released acids; therefore such conditions facilitated leaching of soluble salts and decreased soil salinity.

Table 4 Effect of mineral N, biofertilizer, and compost on soil properties during 2010/2011 and 2011/2012 seasons

Treatment	pH [1:2.5]	EC dSm^{-1}	Cations $mmol_c\ L^{-1}$				Anions $mmol_c\ L^{-1}$				SAR	ESP
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Cl^{-}	$CO_3^{=}$	HCO_3^{-}	$SO_4^{=}$		
2011–2012												
Control	8.10	13.5	10.5	21.9	102	0.78	90.1	Nil	8.26	42.3	25.4	36.6
N1 (119 kg N ha^{-1})	8.08	12.7	13.7	18.1	85.6	0.79	78.2	Nil	7.21	33.0	21.4	30.7
N2 (179 kg N ha^{-1})	8.07	12.6	14.3	17.0	94.2	0.82	88.3	Nil	6.22	32.2	23.8	34.2
Bio	8.04	10.3	12.0	17.5	82.2	0.83	75.2	Nil	7.83	29.7	21.4	30.6
Bio + N1	8.01	10.5	14.3	16.2	72.0	0.93	63.1	Nil	6.10	34.3	18.4	26.2
Bio + N2	8.05	11.0	15.6	16.2	70.0	0.92	62.0	Nil	5.69	35.1	17.6	24.9
Compost	8.02	10.8	13.5	16.9	79.4	0.89	70.5	Nil	6.49	34.2	20.4	29.0
Compost + N1	8.03	11.1	12.4	16.9	83.8	0.86	77.4	Nil	6.33	30.6	21.9	31.4
Compost + N2	8.00	11.4	15.8	16.0	74.7	0.96	60.6	Nil	5.23	36.9	18.7	26.6
Grand mean	8.05	11.6	13.6	17.4	82.7	0.86	73.9	Nil	6.60	34.3	21.0	30.0
2012–2013												
Control	8.06	13.3	14.5	19.7	98.3	0.82	82.4	Nil	8.22	43.1	23.8	34.1
N1 (119 kg N ha^{-1})	8.02	10.7	15.8	17.3	80.8	0.84	74.3	Nil	7.17	39.5	19.9	28.3
N2 (179 kg N ha^{-1})	8.02	11.5	15.8	17.1	73.1	0.85	66.1	Nil	7.08	33.8	18.0	25.6
Bio	8.02	9.07	14.7	20.7	69.6	0.86	60.5	Nil	6.35	33.5	16.6	23.4
Bio + N1	7.97	9.20	15.2	18.0	53.9	0.97	48.3	Nil	5.42	37.3	12.6	17.5
Bio + N2	8.00	10.6	15.4	17.2	58.5	0.93	49.4	Nil	5.43	37.6	14.9	20.3
Compost	8.00	9.31	17.7	18.2	56.6	0.94	52.1	Nil	5.89	35.5	13.4	18.6
Compost + N1	8.01	9.34	15.0	17.3	59.9	0.85	51.2	Nil	6.28	35.8	14.9	20.9
Compost + N2	7.95	9.39	17.8	17.0	50.7	0.95	42.0	Nil	5.10	36.8	12.7	17.7
Grand mean	8.01	10.3	15.8	18.1	66.8	0.89	58.5	Nil	6.33	37.0	16.3	22.9

3.1.3 Soluble Ions

Data presented in Table 4 indicate that Ca^{++} and K^{+} increased while Na^{+} and Mg^{++} decreased. The treatment (compost + N2) seemed to be generally of the most superior effect on Ca^{++} and K^{+}.

Soluble anions, i.e., Cl^{-}, HCO_3^{-}, and SO_4^{--}, decreased due to the bio-, organic, and mineral N fertilization in soil after harvest for the two growing seasons 2011/2012 and 2012/2013. No free carbonates were detected in soil extracts. Bicarbonates which ranged from 8.26 to 5.23 $mmol_c\ L^{-1}$ for 2011/2012 season and 8.22–5.10 $mmol_c\ L^{-1}$ for 2012/2013 season were generally of the highest concentrations. Lowest values of Cl^{-} and HCO_3^{-} (60.6 and 5.23 $mmol_c\ L^{-1}$, respectively) at 2011/2012 season and (42.0 $mmol_c\ L^{-1}$ and 5.10 $mmol_c\ L^{-1}$, respectively) at 2012/2013 season were obtained under (compost + N2), while for SO_4^{--} the treatment of biofertilization gave the lowest values (29.7 and 33.5 at 2011/2012 season and 2012/2013 season, respectively).

3.1.4 Soil Sodicity

Soil sodicity in terms of exchangeable sodium percentage (ESP) of the soil as well as sodium adsorption ratio (SAR) of the soil-paste extract decreased considerably as affected by the fertilizer treatments (Table 4). Generally, all treatments resulted in a sharp decrease in SAR and ESP values. The SAR decreased from 25.4 for control to 17.6 for soil treated with Bio + N2, thus exhibiting a decrease of 30.7% in 2011/2012 season. The SAR decreased from 23.8 (control) to 12.6 due to the treatment Bio + N1 corresponding to a decrease performance of 47.1% in 2012/2013 season. The ESP followed a trend similar to that of SAR, that is, the ESP values showed a decrease ranged between 32.0 and 48.7% due to the treatment (Bio + N2) in 2011/2012 and (Bio + N1) in 2012/2013 seasons, respectively.

3.1.5 Available Macronutrients (N, P, and K)

Data presented in Table 5 show the available N, P, and K ($mg\ kg^{-1}$) as affected by the used treatments and their combinations on the studied soil. Data revealed that the available N, P, and K increased as affected by the treatments of mineral, organic, and biofertilization and their combinations. Available N ranged between 33.1 and 56.1 $mg\ kg^{-1}$ for 2011/2012 season and 37.2 and 63.1 $mg\ kg^{-1}$ for 2012/2013 season. Available P ranged between 3.58 and 4.33 $mg\ kg^{-1}$ for 2011/2012 season and 3.64 and 4.83 $mg\ kg^{-1}$ for 2012/2013 season. Available K ranged between 198 and 229 $mg\ kg^{-1}$ in 2011/2012 season and 201 and 236 $mg\ kg^{-1}$ in 2012/2013 season. The soil treated with compost + N2 gave the highest values of available N, P, and K. The positive effect of organic N source is partially due to a slow release of N from manure, as suggested by [60].

Table 5 Available macro- and micronutrients in soil after harvest during 2010/2011 and 2011/2012 seasons

Treatment	Available macronutrients (mg kg^{-1})			Available micronutrients (mg kg^{-1})		
	N	P	K	Fe	Mn	Zn
2011–2012						
Control	33.1	3.58	198	6.53	2.58	0.96
N1 (119 kg N ha^{-1})	44.2	3.72	193	6.76	2.66	0.98
N2 (179 kg N ha^{-1})	47.2	3.80	198	6.83	2.72	1.00
Bio	38.1	3.64	201	6.59	2.61	0.98
Bio + N1	48.2	4.22	215	7.12	2.89	1.07
Bio + N2	50.1	4.26	219	7.16	2.96	1.08
Compost	39.2	4.18	205	7.09	2.84	1.03
Compost + N1	52.1	3.77	222	7.63	2.65	0.98
Compost + N2	56.1	4.33	229	7.23	3.01	1.12
Grand mean	45.4	3.94	209	6.99	2.77	1.02
$LSD_{0.05}$	3.62	0.34	2.03	0.12	0.18	NS
2012–2013						
Control	37.2	3.64	201	5.63	2.65	1.02
N1 (119 kg N ha^{-1})	46.2	3.78	204	6.74	2.77	1.06
N2 (179 kg N ha^{-1})	53.4	3.89	207	6.79	2.82	1.09
Bio	41.2	3.76	208	5.66	2.71	1.04
Bio + N1	54.2	4.29	225	7.04	3.06	1.14
Bio + N2	59.1	4.76	232	7.08	3.12	1.15
Compost	43.3	4.25	214	7.81	3.02	1.10
Compost + N1	57.0	3.80	229	5.71	3.07	1.06
Compost + N2	63.1	4.83	236	7.12	3.16	1.18
Grand mean	50.5	4.11	217	6.62	2.93	1.09
$LSD_{0.05}$	3.21	0.50	3.72	1.01	NS	NS

The P and K fractions added through organic manures upon its decomposition with time may account for the increases in both P and K [61]. Also the production of organic and inorganic acids during the degradation of such organic materials, which led to a decrease in soil pH, reduces K fixation and produces more chelating ions, leading to an increase in available forms of elements in the rhizosphere zone. These results are in agreement with those obtained by [62].

The corresponding relative increases were 69% and 70% in 2011/2012 and 2012/2013 seasons for available N, 20.9% and 32.7% in 2011/2012 and 2012/2013 seasons for available P, and 15.7% and 17.4% in 2011/2012 and 2012/2013 seasons for available K. This was found to be obvious due to the treatment compost + N2.

3.1.6 Available Micronutrients (Fe, Mn, and Zn)

The concentrations of Fe and Mn in soil at the end of the experiment significantly increased due to the application of compost, urea, and biofertilizer in comparison with the untreated control treatment except for Mn in 2011/2012 season. Zn also increased due to the different treatments; however, the increases occurred were insignificant. This fact holds true for the two seasons under study. This may be due to the vital role of compost which contains microorganisms that make these nutrients more available in the soil. Also, compost may play a vital role in increasing nutrient availability through the processes of chelating, biochemical processes, and production of several organic acids during decomposition of compost as reported by [63].

Also, bacteria cause some micro-nutritive elements such as Fe, Mn, and Zn to release in available forms in soil through breakdown of organic materials in the soil [64]. The highest available Fe values (7.63 and 7.91 mg kg^{-1}) were obtained under the treatments of compost + N1 in 2011/2012 season and compost in 2012/2013 season, respectively. The highest available Mn and Zn contents in soil were 3.01 and 1.12 mg kg^{-1}soil in 2011/2012 season and 3.16 and 1.18 mg kg^{-1}soil in 2011/2012 season, respectively, and were obtained due to the treatment of compost + N2.

3.2 Growth Parameters and Yield of Barley

3.2.1 Growth Parameters

Some growth parameters of barley plants are shown in Table 6. Application of urea, compost, and biofertilizers solely or in combination with urea significantly increased grain weight *per* spike and 1,000 grain weight of barley as compared to the untreated (control). This was found true for both the growing seasons 2011/2012 and 2012/2013, except for grain weight *per* spike in 2011/2012 season. The highest grain weight *per* spike and 1,000 grain weight were recorded in the plants treated with compost + N2 which caused increases of about 31.8% and 77.7% in 2011/2012 season and 30.7% and 71.2% in 2012/2013 season, respectively. Application of N1 (119 kg N ha^{-1}) and N2 (179 kg N ha^{-1}) increased grain weight *per* spike by 10.9% and 17.3% in 2011/2012 and 12.3% and 16.7% in 2012/2013, respectively, and increased 1,000 grain weight by 22.0% and 35.8% in 2011/2012 and 18.6% and 30.7% in 2012/2013, respectively. This shows the positive effect of urea which would enhance the decomposers of the organic matter, thereby releasing the nutrients in available form. Previous studies justified the positive effects of nitrogen application [24, 65] and biofertilizer inoculation [27].

3.2.2 Straw and Grain Yields

As shown in Table 6, N application, biofertilizer, and compost as well as their combinations significantly increased straw and grain yields of barley plants. The treatments followed the following descending order according to their effects

Table 6 Effect of urea, biofertilizer, and compost on yield and yield components of barley during 2010/2011 and 2011/2012 seasons

Treatments	Grain weight/spike^{-1} (g)	1,000 grain weight (g)	Yield (Mg ha^{-1})			Yield efficiency (%)	Harvest index (HI) %
			Straw	Grain	Biological		
First season [2011–2012]							
Control	1.10	28.2	0.874	0.355	1.23	40.6	28.9
N1 (119 kg N ha^{-1})	1.22	34.4	1.86	1.19	3.05	64.0	39.0
N2 (179 kg N ha^{-1})	1.29	38.3	2.25	1.64	3.89	72.9	42.2
Bio	1.15	35.5	0.960	0.702	1.66	73.1	42.3
Bio + N1	1.30	41.3	2.52	2.29	4.81	90.9	47.6
Bio + N2	1.38	48.1	2.81	2.59	5.40	92.2	48.0
Compost	1.20	40.5	1.38	0.73	2.11	52.9	34.6
Compost + N1	1.36	46.2	2.72	2.52	5.24	92.7	48.1
Compost + N2	1.45	50.1	2.95	2.67	5.62	90.5	47.5
Grand mean	1.27	40.3	2.04	1.63	3.67	74.4	42.0
$LSD_{0.05}$	NS	3.341	0.173	0.320	3.691		
Second season [2012–2013]							
Control	1.14	32.3	0.886	0.388	1.27	43.8	30.6
N1 (119 kg N ha^{-1})	1.28	38.3	1.96	1.25	3.21	63.8	38.9
N2 (179 kg N ha^{-1})	1.33	42.2	2.22	1.46	3.67	65.8	39.8
Bio	1.22	35.2	0.993	0.733	1.73	73.8	42.4
Bio + N1	1.36	44.4	2.58	2.35	4.93	91.1	47.7
Bio + N2	1.42	52.2	2.85	2.69	5.53	94.4	48.6
Compost	1.26	42.2	1.01	0.75	1.76	74.3	42.6
Compost + N1	1.43	51.4	2.61	2.36	4.97	90.4	47.5
Compost + N2	1.49	55.3	2.87	2.72	5.60	94.8	48.6
Grand mean	1.33	43.7	2.00	1.63	3.63	76.9	43.0
$LSD_{0.05}$	0.085	4.413	0.195	0.403	3.726		

on straw and grain yields: compost + N2 > Bio + N2 > compost + N1 > Bio + N1 > N2 > N1 > compost > Bio > control. This trend was found to be true for both the two growing seasons. The plots treated with organic manure became more enriched in the released nutrient, especially the micronutrients, which directly or indirectly in the valve in formation of starch, protein, and other biological components through their roles in the respiratory and photosynthesis mechanisms as well as in the activity of various enzymes. Also, the organic manure improves soil's physicochemical, hydrological, and biological characteristics, which facilitate nutrient uptake by barley, and hence increases barley straw and grain yields [66]. Application of biofertilizer is suggested as a sustainable way for increasing crop yields due to the plant growth-promoting substances produced by the biofertilizer [22], in addition to the reasonable quantity of atmospheric nitrogen fixed by *Rhizobium radiobacter* [21]. Therefore, the general physiological status of the plants as indicated by the dry weight always exhibits positive response to the use of biofertilizer.

Piccinin [29] showed that the grain yield of wheat improved when wheat plants were grown with a combination of chemical N and biofertilizer inoculation. These results are in agreement with those obtained by [37, 40].

For the 2011/2012 season, the highest straw and grain yields were 2.95 and 2.67 Mg ha^{-1}, while for the 2012/2013 season, they were 2.87 and 2.72 Mg ha^{-1}, respectively. The values were obtained due to the addition of compost + N2 treatment which resulted in relative increments of 179% and 652% in 2011/2012 season as well as 224% and 601% at 2012/2013, respectively.

3.2.3 Grain Yield Efficiency and Harvest Index

Values of yield efficiency as affected by mineral, bio-, and organic N fertilizers whether applied solely or in combination are shown in Table 6. Grain yield efficiency, which is the ratio of grain yield to straw yield at maturity, varied between 40.6% and 92.7% in the growing season of 2011/2012 and 43.8% and 94.8% in 2012/2013 growing season. The plants treated with compost + N1 gave the highest yield efficiency followed by biofertilizer + N2 treatment. The values were 92.7% and 92.2% for the season of 2011/2012 giving increases of 128% and 127%, respectively, while the values were 94.8 and 94.4% observed under the treatments of compost + N2 and biofertilizer + N2 for the season of 2012/2013 giving increases of 116% and 115%, respectively.

Harvest index of barley increased due to the treatments of urea, biofertilizer, and compost solely or in combination with N fertilization. Harvest index of plants treated with compost + N1 in season 2011/2012 was the highest giving an increase of 66.4% as compared to the control. The effects of compost + N2 and biofertilizer + N2 treatments were equal and gave almost the same highest value (48.6%) in the growing season of 2012/2013. The favorable effect of mineral N fertilization due to N is essential for plant growth. Therefore, the increase in N fertilization rate would increase metabolic processes and physiological activity rates, and thus, increased yield with good quality of grains would occur [67].

3.3 Total Proline Content

Data presented in Table 7 show the effect of nitrogen fertilization, biofertilization, and compost on the total proline content in dry weight of grains. The plants which received fertilizers showed significant decreases compared to the control (without fertilizers) which gave the highest proline contents 16.0 and 16.6 g kg^{-1} dry leaves in 2011/2012 and 2012/2013 seasons, respectively. These treatments can be arranged due to their effects on proline content in the following order: control > N2 > N1 > compost + N2 > compost + N1 > biofertilizer + N2 > biofertilizer + N1 > compost > biofertilizer. This trend was found true for 2011/2012 and 2012/2013 seasons. Nour El-Din [68] reported that proline accumulation is a

Table 7 Effect of urea, biofertilizer, and compost on concentration proline content, protein content, and protein yield as well as N content and uptake by barley during 2010/2011 and 2011/2012 seasons

Treatment	Proline ($g\ kg^{-1}$) dry weight	Protein ($g\ kg^{-1}$)	Protein yield ($kg\ ha^{-1}$)	N content ($g\ kg^{-1}$)		N uptake ($kg\ ha^{-1}$)	
				Straw	Grain	Straw	Grain
2011/2012							
Control	16.0	65.9	23.4	7.97	11.3	6.96	4.61
N1 (119 kg N ha^{-1})	15.3	79.9	95.1	8.58	13.7	16.0	16.1
N2 (179 kg N ha^{-1})	15.4	85.7	141	9.68	14.7	21.8	24.0
Bio	11.2	79.3	55.7	8.24	13.6	7.91	9.62
Bio + N1	12.8	120	275	9.91	20.5	25.0	46.9
Bio + N2	13.9	125	324	10.1	21.5	28.5	55.6
Compost	12.2	88.0	64.2	8.54	15.1	11.8	11.0
Compost + N1	14.6	124	313	10.2	21.2	27.8	53.5
Compost + N2	14.9	128	342	10.8	22.0	31.9	58.6
Grand mean	14.0	101	182	9.34	17.3	19.7	31.1
$LSD_{0.05}$	0.141	0.875	0.768	0.074	0.152	6.916	12.53
2012/2013							
Control	16.6	69.2	26.8	8.24	11.9	7.30	5.01
N1 (119 kg N ha^{-1})	15.9	82.8	104	8.86	14.2	17.4	17.7
N2 (179 kg N ha^{-1})	16.0	89.2	130	9.83	15.3	21.8	22.3
Bio	11.7	80.8	59.2	8.64	13.9	8.58	10.4
Bio + N1	12.8	125	294	10.3	21.5	26.6	50.5
Bio + N2	14.5	126	339	11.1	21.6	31.5	58.0
Compost	12.3	88.2	66.2	9.17	15.1	9.24	10.6
Compost + N1	15.3	131	309	10.7	22.5	27.8	53.1
Compost + N2	15.5	132	359	11.3	22.6	32.3	61.6
Grand mean	14.5	103	187	9.78	17.7	20.3	32.1
$LSD_{0.05}$	0.170	1.322	0.987	NS	0.281	6.928	17.80

common metabolic response of higher plants to salinity stress. Also, compost treatments decreased the proline accumulation in wheat plants grown in saline soil. These results agree with those obtained by [53, 69].

The biofertilizer inoculation with *Rhizobium radiobacter* sp. treatment decreased proline content by 23.8 and 29.5% at 2011/2012 and 2012/2013 seasons, respectively, compared to the control.

3.4 Grain Protein Content and Protein Yield

It can be seen from results presented in Table 7 that the grain protein content and grain protein yield of barley significantly increased as affected by the treatments of urea, bio-inoculation with *Rhizobium*, and compost as well as their combinations. Mabrouk [70] found that bio-mineral and organic-mineral fertilization treatments were more effective in increasing the protein content of peanut plants as compared with the individual mineral fertilization. The favorable effect of mineral N fertilization is attributed to its role as one of the most important constituents of all proteins and nucleic acids and hence protoplasm and chlorophyll [71]. As the level of N supply increases, the extra protein produced allows the plant leaves to grow larger, and consequently photosynthesis increases. Therefore, the increase in N fertilization level led to an increase in metabolic processes and physiological activities necessary for more plant organ formation, more dry matter accumulation, and enhancing the grain hilling rate, which finally increases the amount of protein in grain. These results are in accordance with those reported by [22, 72]. The highest values of protein content (128 and 132 g kg^{-1}) were obtained due to the treatment compost + N2 in 2011/2012 and 2012/2013 seasons representing increase percentage of 94.2% and 90.8%, respectively.

Regarding the grain protein yield, results followed a trend similar to that of protein content and followed the sequence: compost + N2 > Bio + N2 > compost + N1 > Bio + N1 > N2 > N1 > compost > Bio. This promoting effect could be attributed to the integrated effect of highly humified organic materials plus the bioeffect of nitrogen-fixing bacteria on increasing the available nutrients and supporting them as a storehouse for plant growth against the adverse conditions, e.g., high salinity and sodicity, and accordingly maximizing the biological yield and grain quality of barley [62]. The highest values of protein yield (342 and 359 kg ha^{-1}) were obtained due to the same treatment which resulted in the highest protein content in the two growing seasons, respectively.

3.5 Macronutrient Content

Data in Tables 7 and 8 show that N, P, and K uptake increased significantly due to addition of urea, biofertilizer, and organic N sources and their combinations. Also, the treatment consisting of compost + N2 was superior for increasing the uptake of N, P, and K as compared to the other treatments. This promoting effect could be related to the N supplementary effect of N2-fixing bacteria (used as bio-N fertilizer) to plants due to their ability to fix free molecular atmospheric nitrogen. The role of these bacteria is to improve the availability of soil elements (Table 5) through secreting chelating substances which are important for solubilizing sparingly soluble inorganic compounds to more available forms for plants' uptake [24, 27].

On the other hand, the positive effect of organic manures might reflect the different characteristics of the added organic manures (their chemical composition and nutritional status). The organic manures might create favorable soil physical and chemical conditions, which affect the solubility and availability of nutrients and thus uptake of nutritional elements. Moreover, the released N is known to be an essential nutrient for plant growth and development involved in vital plant functions such as

Table 8 Uptake of P and K as well as Fe, Mn, and Zn by barley as affected by bio-, mineral, and organic N fertilization during 2011/2012 and 2012/2013 seasons

	Macronutrient uptake (kg ha^{-1})				Micronutrient uptake (g ha^{-1})					
	P		K		Fe		Mn		Zn	
Treatment	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain
2011/2012										
Control	1.95	1.19	23.4	4.98	46.2	27.7	27.3	15.6	12.6	7.32
N1 (119 kg N ha^{-1})	4.64	4.09	51.2	17.1	121	103	68.7	58.2	35.2	35.2
N2 (179 kg N ha^{-1})	6.38	5.90	65.2	24.1	161	154	95.5	85.9	48.2	51.3
Bio	2.29	2.90	26.1	11.2	52.5	58.5	32.7	35.0	15.2	14.5
Bio + N1	7.11	10.2	77.2	37.1	178	213	104	112	55.9	84.9
Bio + N2	8.55c	12.3	86.0	44.0	221	268	131	144	77.3	93.6
Compost	4.41	3.15	37.9	11.9	80.3	61.3	49.7	38.5	26.4	18.5
Compost + N1	9.28	13.0	83.9	46.2	208	248	120	142	69.5	94.2
Compost + N2	11.0	15.2	91.6	50.4	243	291	151	161	89.4	105
Grand mean	6.18	7.55	60.3	27.4	146	158	86.7	88.0	47.7	56.1
$LSD_{0.05}$	1.835	3.513	24.27	13.02	42.38	72.37	25.57	44.65	17.31	28.18
2012/2013										
Control	2.21	1.33	23.9	5.53	47.1	30.9	29.3	18.2	13.5	8.37
N1 (119 kg N ha^{-1})	6.14	5.12	56.0	18.5	135	112	80.6	67.9	42.1	40.6
N2 (179 kg N ha^{-1})	7.34	5.93	64.6	22.0	165	138	97.8	79.8	51.5	51.0
Bio	2.77	3.30	28.3	11.8	59.3	61.3	36.1	38.4	18.2	18.6
Bio + N1	8.10	10.8	81.6	39.6	189	233	115	132	63.0	81.2
Bio + N2	10.0	14.1	89.0	46.2	235	285	143	156	86.4	103
Compost	2.94	3.68	27.9	12.6	62.6	65.0	35.6	42.8	20.1	22.9
Compost + N1	8.97	12.8	82.0	43.5	207	249	126	142	71.5	86.3
Compost + N2	10.7	15.6	91.8	53.2	250	306	161	175	95.8	115
Grand mean	6.57	8.07	60.6	28.1	150	165	91.6	94.5	51.3	58.6
$LSD_{0.05}$	2.693	4.918	26.63	10.15	41.81	77.13	29.44	42.69	18.37	27.45

photosynthesis, DNA synthesis, protein formation, and respiration [34]. These results coincide with the results of [37, 72].

The individual effect of urea, compost, and biofertilizer treatments showed a descending increase in the order (N2 > N1 > compost > biofertilizer) for N, P, and K uptake by straw and grains during the growing season 2011/2012. The same trend was found true at 2012/2013 season except for K uptake by straw which followed the order (N2 > N1 > biofertilizer > compost).

The effect of compost and biofertilization in combination with urea, on increasing N, P, and K uptake, followed the order (compost + N2 > biofertilizer + N2 > compost + N1 > biofertilizer + N1) for N uptake by straw and grains as well as K uptake by straw during the two growing seasons as well as P and K uptake by grains at the second season 2012/2013. However, the followed sequence, compost + N2 > compost + N1 > biofertilizer + N2 > biofertilizer + N1, characterized P and K uptake by grain at the first season and P uptake by straw at the second season.

The highest values of N, P, and K uptake during the two growing seasons were achieved due to the application of compost + N2.

3.6 Micronutrient Content

Values of Fe, Mn, and Zn uptake by barley plants as affected by the application of urea, compost, and biofertilization solely or in combination were shown in Table 8. The uptake of Fe, Mn, and Zn followed a pattern similar to that shown by the macronutrient where they increased significantly by the addition of the aforementioned fertilization treatments during the two growing seasons. Compost + N2 treatment was most effective on the uptake of Fe, Mn, and Zn as compared to the other treatments. This trend was found true for the two growing seasons 2011/2012 and 2012/2013.The percentage responses of Fe, Mn, and Zn uptake by barley straw over the control were 426, 453, and 610% in 2011/2012 and 431, 449, and 610% in 2012/2013, respectively. Also, the increased percentages reached to 950%, 932%, and 1,334%, respectively, by barley grains in the first growing season and 890, 862, and 1,274% in the second growing season, respectively. These findings are in agreement with those by [54, 59] who reported that the application of compost and biofertilizer combined with mineral N fertilizer caused pronounced increases in soil available micronutrient contents (Fe, Mn, Zn, and Cu) during two seasons under rice cropping. These increases may be attributed to the role of organic sources in improving these micronutrients' availability which was likely attributed to several reasons: (1) releasing of these nutrients through microbial decomposition of organic matter; (2) enhancing the chelation of metal ions by fulvic acid, organic legends, and/or other organic functional groups which may promote the mobility of metal from solid to liquid phase in the soil environment; and (3) lowering the redox status of iron and manganese, leading to reduction of higher Fe^{3+} and Mn^{4+} to Fe^{2+} and Mn^{2+} and/or transformation of insoluble chelated forms into more soluble ions.

3.7 N Utilization Efficiencies

The efficiency of applied N is considered an important criterion besides the N requirements to obtain maximum economic yield. Accordingly, the efficiencies of the applied nitrogen for the different bio- and organic treatments were calculated, and the results were shown in Table 9.

3.7.1 Nitrogen Use Efficiency (NUE) kg kg^{-1}

The values of nitrogen use efficiency show that the inoculation with *Rhizobium radiobacter* sp. increased NUE than the other treatments. On the other hand, application of compost decreased NUE obviously, and this may be because the nitrogen in the organic compost was not readily available for plant and therefore the total N applied by fertilizer plus compost content (denominator) was much lower than the actual values. These results are in line with those obtained by [72] who found that the inoculation with *B. japonicum* increased NUE and nitrogen uptake efficiency compared with the un-inoculated treatments. Also, the values of NUE markedly decreased as the nitrogen addition rate increased. Values of NUE ranged from 9.17 to 19.2 at 2011/2012 season and 8.16 to 19.7 at 2012/2013 season. The highest NUE value 19.7 kg kg^{-1} was obtained at the second growing season when plants were treated with urea with *Rhizobium radiobacter* plus the low rate of urea N1 (119 kg N ha^{-1}) which increased the efficiency use of urea fertilizer by 87.6% compared with the treatment that received urea (119 kg N ha^{-1}) only.

3.7.2 Nitrogen Agronomic Efficiency (NAE) kg kg^{-1}

The NAE parameter (the plant's ability to increase the yield in response to N fertilization levels) kg grain/kg N applied followed the same trend shown for the NUE and apparent nitrogen recovery (ANR); hence, the increase of N rate decreased the NAE values. The above three traits which behaved similarly showed that plants absorb more N when it is of low level in the soil. As the level of N increased, the relative absorption of N decreased. The highest NAE values (13.3 and 13.6 kg kg^{-1} at 2011/2012 and 2012/2013 seasons, respectively) were obtained due to the treatment of Bio + urea N1 (119 kg N ha^{-1}) causing increases of 90.5% and 88.4%, respectively, compared with the treatment that received urea (119 kg N ha^{-1}).

3.7.3 Apparent Nitrogen Recovery (ANR)

The ANR parameter indicates the ability to increase N uptake in response to N applied and the proportions of N fertilizer recovered by the plants. The greatest increases were obtained when 119 kg N ha^{-1} was added in combination with

Table 9 NUE, NAE (kg kg^{-1} N), and ANR (%) of barley as influenced by urea, compost, and biofertilization during 2011/2012 and 2012/2013 seasons

Season	Treatment								
	Control	N1, 119 (kg N ha^{-1})	N2, 179 (kg N $ha^{-1)}$	Bio	Bio + N1	Bio + N2	Compost	Compost + N1	Compost + N2
Nitrogen use efficiency, NUE (kg kg^{-1} N)									
2011/2012	0.00	9.96	9.17	0.00	19.2	14.5	8.08	12.1	9.93
2012/2013	0.00	10.5	8.16	0.00	19.7	15.0	8.34	11.3	10.1
Nitrogen agronomic efficiency, NAE (kg kg^{-1} N)									
2011/2012	0.00	6.98	7.19	0.00	13.3	10.5	4.13	8.59	7.23
2012/2013	0.00	7.22	5.99	0.00	13.6	10.9	4.03	7.72	7.35
Apparent nitrogen recovery, ANR (%)									
2011/2012	0.00	9.66	10.8	0.00	31.3	25.7	7.10	20.3	17.7
2012/2013	0.00	10.7	9.66	0.00	33.7	26.5	6.21	20.3	18.9

bio-inoculation and gave 31.3 and 33.7% recovery in the two growing seasons, respectively. This shows that the application of the low rate of nitrogen caused an enhancement of plant growth, causing the roots to explore a greater soil volume and absorb more N from the soil. The lower N recovery occurred at the N2 (179 kg N ha^{-1}) rate indicates the considerable expansion of the root system in the rhizosphere, and more N must have been released from the indigenous N in the soil for plant uptake. The lower N recovery in compost treatment was due to lower uptake of N by grains compared to the other treatments.

The combined use of organic and inorganic nutrient sources may have contributed to better synchrony of nutrient availability to the crop, which was reflected in higher grain yield and biomass production. Also, the combined application of organic sources and fertilizer may provide more favorable conditions for plant growth. The use of organic sources provides not only nutrients in available forms but also organic matter, which is an ecological method of sustaining soil productivity. Thus, it is suggested to use a combination of bio-, organic, and inorganic fertilizer to achieve the highest yield and best grain quality and ensure at the same time environmental conservation.

4 Conclusions

It could be concluded that application of biofertilizers and compost is very important due to their effect on improving soil physical, chemical, and biological properties; besides compost represents a storehouse for all essential macro- and micronutrients. The applied organic manure led to improving barley grain quality. Also, from the economical point of view, the use of organic manure decreases the needed amounts of chemical fertilizers and produces higher yield and better quality of barley grains with a relatively lower cost. Finally, under the current experimental conditions, it could be concluded that this work in hand granted evidence to the effective role of applied compost manure at the rate of 6 Mg ha^{-1} in combination with urea at the rate of 179 kg N ha^{-1} to achieve the greatest growth parameters of barley plants under salinity and sodicity stresses.

5 Recommendations

Currently, there is a gap of more than 10 million tons of plant nutrients between consumption through cultivated crops and chemical fertilizers added. In the context of both the financial cost and the environmental impacts of chemical fertilizers, the excessively high use of excess chemicals cannot be sustained for future periods due to the high cost. In this context, organic and biofertilizers would be the viable option for farmers to increase productivity per unit area, but more conclusive data through additional studies are required.

For sustainable agriculture, there must be a positive link between the nutrients applied to the soil and crop uptake. This link could be more firm and sustainable if we employ an integrated approach, i.e., the use of bio-augmented N-enriched organic fertilizer. In this way, we would be employing a sustainable approach to meet the needs of crops for N in an environment-friendly way. The use of this approach would not only be helpful in the restoration of degraded soils but would also be helpful in minimizing organic wastes that could be composted to make organic fertilizer. The product would help the farmers in reducing their expenditures to purchase chemical fertilizers and would also reduce the import budget on a national level. However, a few studies have reported its efficacy under pot and field conditions. More studies under controlled and field condition are needed to confirm these reports. Also, there is a need to find the optimum ratio to mix organic fertilizer and N fertilizer, its time, and rate of application. Relative efficacy of different sources of organic fertilizers to make bio-organo-N could also search out. Their postharvest effects on soil physicochemical properties and on microbial community structure could also be found out in the future. A variety of organisms are involved in N cycling in soils, and microorganisms are probably the most important ones. However, most of the soil microbes have not been cultured successfully [73].

In the future, new culture-independent methods like LMW RNA profiling and PCR based on nucleic acid composition are required to study the function and ecology of microbes involved in nutrient cycling in soils [74]. The techniques mentioned have been found not only independent of culture media composition or growth phase of microorganisms but also are precise and reproducible. These techniques also made it possible to utilize different biotechnological tools like amplification of targeted genes or to quantify their expression. Overall, these techniques have opened new horizons in order to solve out the puzzle related to124 organic fertilizers and to assess which type of inoculants is preferable under different environmental conditions.

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Using Humic Substances and Foliar Spray with *Moringa* Leaf Extract to Alleviate Salinity Stress on Wheat

Abdel-Rahman M. A. Merwad

Abstract Worldwide, particularly in dry regions, soil salinity is one of the most important problems limiting plant growth and productivity of a wide range of horticulture and field crops. The adverse effect of salinity on plants may lead to disturbances in plant metabolism, which consequently lead to a reduction of the plant growth and productivity. The aim of this work was to investigate the effect of humic substance with or without foliar spraying *Moringa* leaf extract (MLE) on wheat yield, photosynthetic pigments, nutrient uptake, and soil characteristics available N, P, and K in saline soil conditions. Results indicated that photosynthetic pigments, nutrient uptake, and available N, P, and K significantly decreased within each humic substance application and MLE with increasing salinity concentration. Under saline conditions, either humic materials or MLE increased growth, plant height and yield parameters (i.e., straw and grains yield, biological yield, weight of 1,000 grain), protein content of the leaf, harvest index, photosynthetic pigments, and proline and NPK-uptake of wheat plants compared to those in the untreated control plants. The highest values of biomass yield, the weight of 1,000 grain, chlorophyll, chlorophyll b, carotenoid concentrations, and NPK-uptake under different salinity levels were observed with application of HA and FA under spraying MLE. Soil pH and EC were decreased with the application of humus materials under soil salinity level. In contrast, organic matter and available nutrients (i.e., N, P, and K) were increased in soils treated with humic materials compared to those in untreated ones.

Keywords Humus materials, *Moringa* leaf extract, Salinity stress, Soil properties, Wheat

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Contents

1 Introduction

Soil salinity is one of the most brutal environmental factors limiting the productivity of crop plants. This is because most of the crop plants are sensitive to salinity caused by high concentrations of salts in the soil. In fact, the area of land affected by it is increasing day by day. For almost all important crops, average yields are only a fraction – somewhere between 20% and 50% of record yields. “These losses are mostly due to drought and high soil salinity, environmental conditions which will worsen in many regions because of global climate change” [1]. An increase in soil salinity commonly results in a reduction of water intake of plants. Passive nutrient uptake of the plants is related to water intake, and any decrease in water availability causes a reduction in the uptake of many plant nutrients [2].

Salinity refers to the total concentration of all soluble salts in the soil, i.e., Cl^-, SO_4^{-2}, or CO_3^- of Na^+, Ca^{+2}, and Ma^{+2} with the most common salt being NaCl [3]. Cornillon and Palliox [4] showed that salts had a negative effect on plant growth, nutrient uptake, and productivity by increasing nutritional imbalance, osmotic stress, and specific ion toxicity. Ahmad [5] reported that increasing soil salinity decreases straw and grain P-uptake of barley plants. Phosphorus (P) concentration in the shoot of wheat was significantly decreased as soil salinity stress increased in both sandy and silty loam soils [6]. Naheed et al. [7] showed a significant effect of salinity stress on P-uptake by root rice and a nonsignificant on P concentration in leaf and grain rice.

Salinity increased the accumulation of Na^+ and decreased the K^+ content in shoots and roots. The Na^+ content of germinating seeds gradually increased, while K^+ content diminished [8, 9]. Nutrient uptake (N, P, K) by wheat plants decreased with increasing soil salinity levels [10]. Nikbakht et al. [11] showed that the addition of humic acid at a rate of 500 mg/L gave the highest values of plant growth, a number of harvested flowers per plant, and N, P, K, Ca, Mg, Fe, and Zn contents of leaves of gerbera plants. Application of humic acid at a rate of 1,000 mg kg^{-1} to saline soil gave an increase in seed germination, plant growth, and macro- and micronutrient contents of tomato [12]. Humic substances might show anti-stress effects under abiotic stress conditions such as unfavorable temperature, pH, salinity, etc. Humic materials could improve growth of plant under soil condition with enhancing nutrient uptake and reducing toxic element uptake [13, 14]. Sharif et al. [15] found that the humus material has indirect effects on plant growth because it improves soil properties, i.e., water holding capacity, permeability, aggregation, hormonal activity, aeration, organic matter mineralization, and solubilization and nutrient availability. The application of chicken manure mixed with humic acid gave an increase in plant height, fresh and dry weight, and N-, P-, and K-uptake of sorghum compared with control [16]. Foidle et al. [17] reported that MLE has plant growth-enhancing capabilities as it is rich in zeatin, carotenoids, phenols, potassium, and calcium. Fuglie [18] reported that spraying MLE increased growth and yield of tomato, peanut, corn, and wheat 20 to 35. The solvent of MLE is a potential source of natural antioxidants [19]. Plant height, tiller number, and biological and grain yields per plant were recorded highest for seed osmopriming plus foliar spray with MLE treatment followed by seed osmopriming [20]. Foliar spray of MLE exhibits highest antioxidant status as compared to other growth enhancers up to moderate salinity (8 dS m^{-1}) except ascorbic acid which continued to be increased up to the highest salinity level (12 dS m^{-1}). The highest values of plant height, leaf area, chlorophylls a and b and carotenoids, yield, straw and grain NPK-uptake, 1,000 grain weight, and protein content were obtained with fulvic acid combined with moringa extract spray [21]. Addition of different humus materials gave the highest values of yield and nutrient uptake of sorghum plants grown on saline soils [22]. The present study aims to investigate the effect of organic materials, i.e., humic and fulvic acids with a foliar spray of *Moringa* leaf extract on soil properties, yield parameters, photosynthetic pigments, and nutrient accumulation of wheat under salinity stress.

2 Experiment Setup and Design

2.1 Design of Experiment and Treatments Under Study

Under Egyptian conditions (Farm of Faculty of Agriculture, Zagazig University), the open greenhouse was used to carry out pot experiment in 2016 season using wheat plants (*Triticum aestivum* L, cv. Sakha 93). Three saline soils of the same texture, but different in their salinities, were collected from three different locations. Soils are collected from El Nubaria, near Alexandria, Egypt. The soil material for the experiment was collected from the surface 0–30 cm of the soil. The experimental design was a factorial arranged as split–split blocks with three soil salinity levels (S1, S2, and S3) as main plot; four humic materials, i.e., untreated; humic acid (HA), fulvic acid (FA), and HA + FA as subplots; and two *Moringa* leaf extract levels (0% and

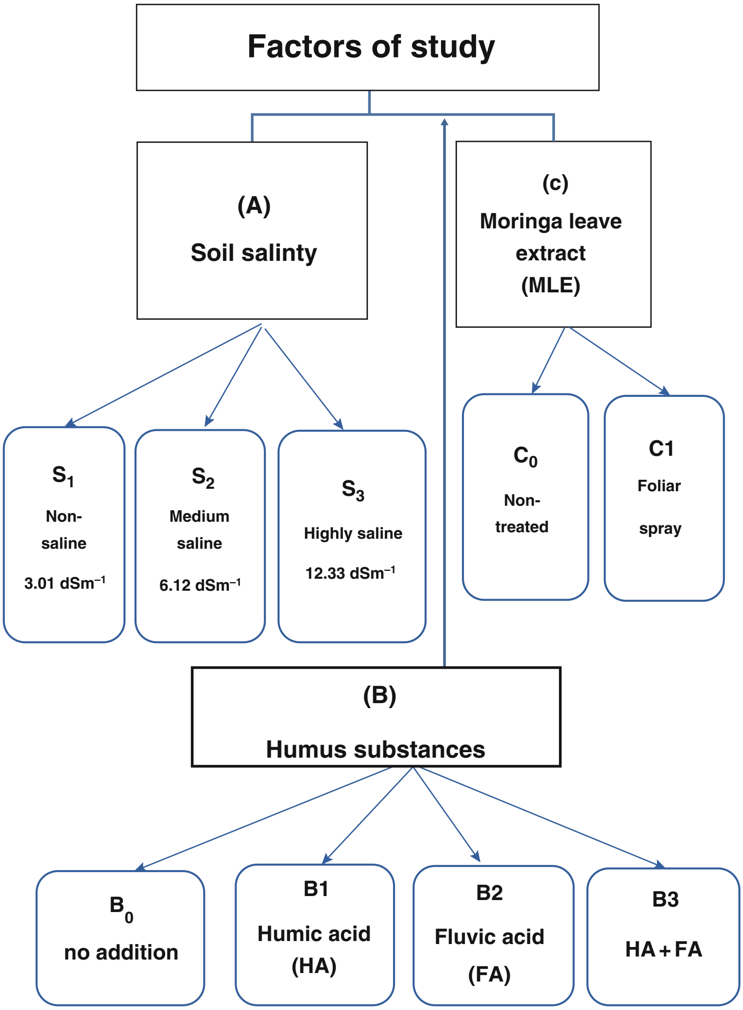

Fig. 1 A flowchart of the methodology

3%) as sub-subplots (Fig. 1). The EC of soils of the three locations (S1, S2, and S3) were 2.50, 6.7, and 11.90 dS m^{-1} which class the three different soils as being mild, moderately, and strongly saline, respectively. The soil was sieved through 5 mm and thoroughly mixed before filling the pots. Closed bottom PVC pots (10-kg capacity each) of 35-cm diameter and 30-cm height were used. Wheat seeds were obtained from the Crops Research Institute, Agriculture Research Centre, Giza, Egypt. Seeds were sown on the 15th of November 2016. Ten seeds were sown in each pot. Twelve days after sowing, plants were thinned to 5 per pot. Physical and chemical properties of the soils were determined according to Black et al. and Jackson [23, 24] (Table 1).

Table 1 Some physical and chemical properties of the soils under study

Soil salinity		S1 (2.50 dS m^{-1})	S2 (6.70 dS m^{-1})	S3 (11.90 dS m^{-1})
Soil particles distribution	Sand %	40	44	38
	Silt %	35	32	33
	Clay %	25	24	29
	Textural class	Loam	Loam	Loam
Cations[a] ($mmol_c$ L^{-1})	Ca^{++}	6.25	15.20	29.5
	Mg^{++}	5.32	19.3	30.0
	Na^{+}	8.02	17.0	37.4
	K^{+}	5.40	15.0	21.7
Anions[a] ($mmol_c$ L^{-1})	CO_3^{-}	–	–	–
	HCO_3^{-}	8.02	20.6	35.9
	Cl^{-}	9.60	16.7	40.3
	SO_4^{--}	7.37	29.2	42.4
EC[a] (dS m^{-1})		2.50	6.70	11.90
pH[b]		7.90	8.0	7.89
Organic matter (g kg^{-1})		6.90	6.81	6.62
$CaCO_3$ (g kg^{-1})		126	123	119
Field capacity (%)		14.0	13.5	15.2
Available macronutrient (mg kg^{-1} soil)	N	40.5	38.2	35.9
	P	7.60	7.31	6.52
	K	80.25	78.54	69.83

[a]Note: Soil paste extract
[b]Soil paste

2.2 *Fertilization and Humic Substances Application*

Soils were fertilized by 0.15, 0.015, and 0.04 g N, P, and K per kg soil in the form of ammonium sulfate (20.5% N), ordinary superphosphate (6.5% P), and potassium sulfate (41.0% K), respectively. The N was added in three equal doses (after 15, 40, and 60 days of sowing). The P and K were added before seeding. Pots were rewatered daily to maintain the soil moisture content at 70% of maximum pot soil capacity. Soil water capacity (SWC) was determined by weighing soil from pots of fully water-saturated soil and then drying to constant weight at 105°C. The weight difference between water-saturated soil and oven-dried soil was taken as a weight of water that represents 100% of SWC. Humic substances, i.e., humic acid (HA) as potassium humate and fulvic acid (FA) as potassium fulvate, were mixed with the soil before planting at the rate of 7 kg ha^{-1} (equivalent to about 0.002 g kg^{-1}).

2.3 Preparation of Moringa *Leaf Extract*

An amount of 20 g of young *Moringa oleifera* leaves was mixed with 675 ml of 80% ethanol (Fig. 2) as suggested by Makkar and Becker [25]. The suspension was stirred using a homogenizer to help maximize the amount of the extract. The solution was filtered using No. 2 Whatman filter paper. MLE was used within 5 h from cutting and extracting (if not ready to be used, the extract or the solution prepared was stored at 0°C and only taken out when needed for use) [22]. The chemical composition of MLE was investigated using Fuglie, Merwad, and Moyo et al. [18, 22, 26] which are represented in Table 2. Extracts used for spray were diluted by 30 ml extract L^{-1} of water (3%). Foliar spraying of *Moringa* leaf extract was done in three equal doses at 40, 70, and 90 days after planting. Control plants (non-treated with MLE) were sprayed with distilled water.

Fig. 2 (**a**) Young *Moringa oleifera* leaves and (**b**) *Moringa* leaf extract (MLE)

(a)

(b)

Table 2 Chemical composition of *Moringa oleifera* leaves per dry weight (dw) (Adapted from Fuglie, Merwad, and Moyo et al. [18, 22, 26])

Component	Value
Protein	273 g kg^{-1} dw
Phosphorus (P)	3.90 g kg^{-1} dw
Potassium (K)	21.70 g kg^{-1} dw
Calcium (Ca)	24.0 g kg^{-1} dw
Magnesium (Mg)	4.5 g kg^{-1} dw
Iron (Fe)	0.582 g kg^{-1} dw
Vitamin A (β-carotene)	163 mg kg^{-1}
Vitamin B1(thiamine)	26 mg kg^{-1}
Vitamin B2 (riboflavin)	210 mg kg^{-1}
Vitamin B3(nicotinic acid)	800 mg kg^{-1}
Vitamin C (ascorbic acid)	1,700 mg kg^{-1}
Vitamin E (tocopheryl acetate)	1,130 mg kg^{-1}

2.4 Plant Harvesting and Analysis

A random sample of three plants was taken from each treatment at 75 days old (booting stage) to record plant vegetative characters, and physiological properties, chlorophyll a, chlorophyll b, and carotenoids, were determined spectrophotometrically [27]. Proline concentration was determined according to the method given by Bates et al. [28].

At harvest, plant samples were separated into straw and grains, dried at 70°C for 72 h, weighed, digested with concentration $H_2SO_4/HCLO_4$, and analyzed for total nitrogen, phosphorus, and potassium [29]. Total nitrogen in the plant was determined using the microKjeldahl method according to Chapman and Pratt [29]. Total potassium in the plant was determined by flame photometer according to Chapman and Pratt [29]. Total phosphorus in the plant was determined colorimetrically using ascorbic acid method [30]. Protein percent "yield quality" in grains was calculated by multiplying N-% × 5.70 [31].

2.5 Soil Analysis

Soil samples were taken at the end of the experiment. The electrical conductivity (EC) of soil paste was determined by using the bridge [24]. Soil pH was measured using glass electrode pH meter in soil paste [24]. Organic matter was determined following Walkelly and Black method, as described by Jackson [24].

Available P was determined using Watanabe and Olsen [30] method, 5 g of soil sample being shaken with 50 ml 0.5 M $NaHCO_3$ solution (pH 8.5) with one gram activated charcoal for 0.5 h and filtered. Available N was determined using the method described by Jackson [24], 5 g of each soil sample was shaken with 50 ml 2 N KCl solution and filtered. Available N was assayed in the soil extract using Kjeldahl apparatus. Available potassium was being extracted by 1 N NH_4OAC solution and assayed by flame photometer [23].

2.6 Statistical Analyses

All the obtained data such as dry weight at tillering and butting stages, straw and grain dry weight, and straw and grain N-, P-, K-uptake were statistically analyzed (LSD at 0.05) according to the method described by Russel [32].

3 Plant Analysis Results

3.1 Yield Parameters and Protein Content of Wheat Plants as Influenced by Humic Substances and Moringa Leaf Extract Under Salinity Stress

In the present experiment, straw and grain yield of wheat plants, biological yield, weight of 1,000 grain, protein content, and harvest index were significantly affected by the interaction between humic substances and *Moringa* leaf extract under different salinity levels (Table 3). The application of various humic substances with MLE gave an increase in yield parameters and quality of wheat grown under salinity stress compared to untreated soils. This finding stands in agreement with those of Nardi et al., Sharif et al., and Abdel-Fattah and Merwad [14, 15, 21]. Khan et al. [33] reported that the application of plant-derived humic acid in alkaline calcareous soils increased plant growth parameters such as spike weight, grain and straw weight, and concentration of nutrients. Singh et al. [34] showed that the addition of humic acid as a foliar or soil application increased plant height, number of branches per plant, leaf area, fruit weight, number of fruits per plant, the volume of fruit, specific gravity, and yield per plant of *Capsicum*. Ali et al. [35] found that the maximum number of florets per spike (11.68) in Megma red variety was recorded at 350 ppm humic acid, while maximum plant height (43.98 cm) in pink rose supreme variety was recorded at 500 ppm humic acid per plant. Dry matter yields of maize plants were significantly affected by the applications of humic acid and boron fertilizer, whereas dry matter yield was decreased by the application of higher B at the rate of 30 mg kg^{-1} without humic acid application [35].

Regarding the mean effect of soil salinity, the data show yield parameters and quality of wheat were decreased by increasing the soil salinity levels. These decreases represent 16%, 26%, 18%, 16%, 16%, and 15% for straw and grain yield of wheat plants, biological yield, the weight of 1,000 grain, protein content, and harvest index, respectively. As mentioned above the plants at three cuts were damaged with the control treatment due to extremely high salinity 11.9 dS m^{-1}. Salts inhibit the growth

Table 3 Effect of humic substances and foliar spray of *Moringa* leaf extract on yield parameters and protein content of wheat plants grown under salinity stress

Salinity level (A)	Humus materials (B)	*Moringa* leaf extract (C)	Straw yield (g plant^{-1})	Grain yield (g plant^{-1})	Biological yield (g plant^{-1})	Weight of 1,000 grains (g)	Protein (g kg^{-1})	Harvest index (%)
S1 (2.5 dS m^{-1})	Without	Without	1.29	0.85	2.14	39.2	75.90	65.9
		With	1.35	0.97	2.32	40.9	81.65	71.9
	HA	Without	1.52	1.32	2.84	45.5	94.88	86.8
		With	1.64	1.36	3.00	46.3	98.90	82.9
	FA	Without	1.40	1.15	2.55	42.1	86.83	82.1
		With	1.44	1.24	2.68	43.7	89.13	86.1
	HA + FA	Without	1.70	1.42	3.12	46.5	121	83.5
		With	1.82	1.57	3.39	48.1	144	86.3
	Mean		1.52	1.23	2.755	44.0375	99.26	81.25
S2 (6.7 dS m^{-1})	Without	Without	1.20	0.70	1.90	35.2	72.45	58.3
		With	1.25	0.76	2.01	36.1	74.75	60.8
	HA	Without	1.36	1.25	2.61	38.9	87.40	91.9
		With	1.40	1.30	2.70	40.0	93.73	92.9
	FA	Without	1.35	0.79	2.14	36.9	81.65	58.5
		With	1.39	0.85	2.24	37.5	87.98	61.2
	HA + FA	Without	1.57	1.36	2.93	42.3	97.75	86.6
		With	1.60	1.45	3.05	44.5	112	90.6
	Mean		1.39	1.06	2.4475	38.9	88.48	76.1
S3 (11.9 dS m^{-1})	Without	Without	0.00	0.00	0.00	00.0	00.0	00.0
		With	1.15	0.68	1.83	34.9	71.88	59.1
	HA	Without	1.32	0.89	2.21	37.2	81.65	67.4
		With	1.35	0.95	2.30	38.4	89.70	70.4
	FA	Without	1.22	0.75	1.97	35.5	77.63	61.5
		With	1.28	0.78	2.06	36.4	81.08	60.9
	HA + FA	Without	1.45	1.20	2.65	40.5	93.73	82.8
		With	1.50	1.32	2.82	41.8	103	88.0
	Mean		1.30	0.90	2.20	37.28	83.38	69.6
LSD 0.05%	A		0.02[a]	0.02[a]	0.12[a]	0.10[a]	1.02[a]	0.57[a]
	B		0.03[a]	0.04[b]	0.10[a]	0.09[b]	1.10[b]	0.56[a]
	C		0.05[b]	0.01[c]	0.13[b]	0.08[b]	0.98[b]	0.71[a]
	ABC		0.01[a]	0.10[a]	0.12[b]	0.05[c]	0.58[a]	0.14[a]

Note: factor of study – A, salinity effects; B, humic substance effects; C, *Moringa* leaf extract effects. *HA* humic acid, *FA* fulvic acid
[a]High significant
[b]Significant
[c]Very high significant

of a plant by increasing specific ion toxicity, osmotic stress, and nutritional imbalance. The extent of damage has increased significantly the salinity during the growing season and reduced the total dry matter accumulation and straw and grain yield of wheat [6].

Concerning the effect of humic substances, data indicate that the application of individual HA or combination with FA gave the higher values of yield parameters and quality of wheat under all salinity levels than single fulvic acid addition in the presence of MLE. The main effects of humic materials are as follows: HA and FA > HA > FA > none.

Data showed that spraying of MLE increased grain dry weight of wheat compared to the untreated ones (Table 3). These increases represent 14%, 3%, 8%, and 10% under S1 (2.5 dS m^{-1}) level for the treatments of untreated, HA, FA, HA + FA, respectively; 9%, 4%, 8%, and 7% under S2 (6.7 dS m^{-1}) level; and 100%, 7%, 7%, and 10% under S3 (11.9 dS m^{-1}) level for the same treatments, respectively. MLE is a highly nutritive multipurpose plant grown for vegetables, livestock fodder, green manure, biogas, medicine, biopesticide, and seed production [18]. Foliar spray with MLE increased plant growth and yield by 20–35% [17, 25, 36–38]. The application of MLE as a foliar spray at a rate of 3% gave the greatest values of fresh and dry weight of sudangrass under soil salinity [22]. The application of 1–4% of aqueous and ethanolic *Moringa* leaf extracts gave an increase of fresh weight of spinach plants which ranged from 126% to 457% and 237% to 620%, respectively [39]. All plants treated with MLE significantly increased shoot and seed yield and protein content of common bean as compared to untreated plants (without foliar spray) under different droughts [40]. All rates of MLE significantly increased fresh pod yield, shoot and seed dry weight, biological yield, 100 seed weight, yield efficiency, and the protein content of pea plants as compared to control [41].

Taking the mean effect of interaction between humic substances and *Moringa* leaf extract into consideration, the data showed that the application of HA combined with FA with spraying of MLE gave significant increase ($P < 0.05$) in straw and grain yield, biological yield, protein content, and weight of 1,000 grain compared to other treatments under different salinity levels.

3.2 *Effect of Humic Substances and Foliar Spray of* **Moringa** *Leaf Extract on Plant Height, Photosynthetic Pigments, and Proline of Wheat Plants Grown Under Salinity Stress*

Results presented in Table 4 show that the application of humic substances and foliar spray of *Moringa* leaf extract significantly ($P \geq 0.05$) increased plant height, chlorophyll a, chlorophyll b, carotenoids, and proline of wheat plants. The greatest values of plant height, photosynthetic pigments, and proline under different soil salinity levels were obtained by HA combined with FA under foliar spray with MLE. Addition of HA significantly increased plant pigments, i.e., chlorophyll a, total chlorophyll, and carotenoid concentrations under calcareous soil conditions [42, 43]. The addition of humus materials at a rate of 5 kg ha^{-1} to saline soils gave the highest values of photosynthetic pigments and proline concentration of sorghum [22].

Table 4 Effect of humic substances and foliar spray of *Moringa* leaf extract on plant height, total chlorophyll, and proline of wheat plants grown under salinity stress

Salinity level (A)	Humus materials (B)	*Moringa* leaf extract (C)	Plant height (cm)	Chlorophyll a (mg g^{-1} f wt)	Chlorophyll b (mg g^{-1} f wt)	Carotenoids (mg g^{-1} f wt)	Proline (μmol p^{-1} g F. wt.)
S1 (2.5 dS m^{-1})	Without	Without	95.3	1.29	0.62	0.55	8.1
		With	95.9	1.32	0.65	0.62	9.6
	HA	Without	98.7	1.45	0.68	0.68	14.2
		With	99.1	1.56	0.71	0.69	16.9
	FA	Without	97.4	1.33	0.75	0.63	10.8
		With	98.1	1.39	0.79	0.65	11.7
	HA + FA	Without	103	1.60	0.84	0.70	19.5
		With	107	1.78	0.89	0.73	22.5
	Mean		99.31	1.47	0.74	0.66	14.16
S2 (6.7 dS m^{-1})	Without	Without	89.9	1.19	0.50	0.42	11.9
		With	90.7	1.23	0.52	0.43	12.8
	HA	Without	95.6	1.36	0.61	0.59	16.8
		With	96.8	1.45	0.64	0.62	18.7
	FA	Without	91.4	1.28	0.68	0.49	14.6
		With	92.6	1.32	0.72	0.55	15.3
	HA + FA	Without	97.2	1.58	0.77	0.60	21.5
		With	98.3	1.67	0.78	0.64	25.2
	Mean		94.06	1.39	0.65	0.54	17.10
S3 (11.9 dS m^{-1})	Without	Without	78.2	1.01	0.43	0.32	14.2
		With	79.5	1.15	0.49	0.34	15.9
	HA	Without	83.4	1.32	0.52	0.46	22.0
		With	85.3	1.34	0.59	0.51	23.6
	FA	Without	81.1	1.19	0.62	0.35	18.9
		With	82.5	1.28	0.65	0.37	20.1
	HA + FA	Without	87.2	1.40	0.68	0.58	24.5
		With	88.7	1.52	0.70	0.60	29.8
	Mean		83.24	1.28	0.59	0.44	21.13
LSD 0.05%	A		1.01[a]	0.03[b]	0.02[c]	0.011[c]	0.25[a]
	B		0.58[c]	0.01[c]	0.013[a]	0.01[b]	0.16[c]
	C		1.0[a]	0.002[c]	0.04[c]	0.02[a]	0.23[a]
	ABC		0.68[a]	0.004[b]	0.003[b]	0.012[c]	0.17[c]

Note: factor of study – A, salinity effects; B, humic substance effects; C, *Moringa* leaf extract effects. *HA* humic acid, *FA* fulvic acid

[a]Significant

[b]Very high significant

[c]High significant

Results showed that plant height and plant pigments of wheat were decreased with increasing soil salinity levels (S1, 2.5, to S2, 11.9 dS m^{-1}). These decreases represent 16% for plant height, 13 for chlorophyll a, 20 for chlorophyll b, and 33 for carotenoids. On the other hand, proline was increased with increasing soil salinity level. These increases represent 33%. This trend was found true under different humus materials with MLE. As mentioned above the plants died off with the control soil due to extremely high salinity (11.9 dS m^{-1}). Merwad [22] found that plant growth and plant pigments of sorghum plants were decreased with increasing salinity of soil, i.e., 3.0–12.0 dS m^{-1}, and proline was increased with increasing salinity of soils. The salinity of the soils has a depressing effect on growth parameters, and photosynthetic pigments were increased with increasing soil salinity levels [44]. Desoky and Merwad [45] showed that the plant growth parameters and total chlorophyll of wheat plants were decreased with increasing salinity of soils. From the data given in Table 4, "it can be concluded that proline was accumulated in leaves of wheat plants grown under salinity stress, so that proline concentration increased linearly with increasing salinity levels" [46, 47].

Taking the mean effect of spraying MLE into consideration, the data show that the foliar spray of MLE gave a significant increase in plant height and photosynthetic pigments and proline concentration of wheat plants compared with untreated plants (without MLE) in the presences of humus materials under salinity stress (see Table 4). This result is in agreement with those obtained by Poustini et al. and Dillard and German [48, 49]. Merwad [41] showed that the addition of MLE as a foliar spray at a rate of 4% gave the highest values of photosynthetic pigments and proline in leaves of the pea plant. Raje and Mestry [50] reported that the greatest value content of vitamins (A, β-carotene); minerals, i.e., Ca, Fe, and K; and natural antioxidants such as ascorbic acid, flavonoid, phenolics, and carotenoids was obtained with leaves of moringa.

3.3 *Effect of Humic Substances and Foliar Spray of* Moringa *Leaf Extract on Straw and Grain NPK-Uptake by Wheat Plants Grown Under Salinity Stress*

The soil application of humus materials increased dry weight and N-uptake of corn, while foliar application of humic acids increased P-, K-, Mg-, Cu-, and Zn-uptake under salinity stress. "Salinity negatively affected the growth of corn; it also decreased the dry weight and the uptake of nutrient elements except for Na and Mn" (Delgado et al. [51]). In many studies, humic and fulvic acid preparations were reported to increase the uptake of mineral elements. Addition of various humic substances, as well as foliar of MLE spray, caused a significant positive effect on straw and grain NPK-uptake (mg $plant^{-1}$) of wheat plants grown in different soil salinity levels (Table 5). The highest values of straw and grain NPK-uptake were obtained with HA combined with FA with MLE spray under S1 (2.5 dS m^{-1}), S2 (6.7 dS m^{-1}), and S3 (11.9 dS m^{-1}) levels. The lowest values of NPK-uptake were obtained with control (untreated soils) under different soil salinity levels [39]. The greatest values of

Table 5 Effect of humic substances and foliar spray of *Moringa* leaf extract on straw and grain NPK-uptake (mg $plant^{-1}$) by wheat plants grown under salinity stress

			Straw			Grains		
Salinity level (A)	Humus materials (B)	*Moringa* leaf extract (C)	N	P	K	N	P	K
S1 (2.5 dS m^{-1})	Without	Without	16.13	2.06	11.22	1.96	12.33	12.33
		With	18.36	2.43	13.77	2.52	14.74	14.74
	HA	Without	23.71	3.95	21.78	5.15	22.44	22.44
		With	27.55	4.92	23.39	6.12	25.70	25.70
	FA	Without	19.60	2.94	17.37	3.34	18.40	18.40
		With	20.59	3.89	19.22	3.97	20.58	20.58
	HA + FA	Without	33.66	5.95	30.10	6.96	27.69	27.69
		With	39.13	8.19	39.56	8.79	34.54	34.54
	Mean		24.34	4.14	23.58	21.32	4.62	21.57
S2 (6.7 dS m^{-1})	Without	Without	13.20	1.68	8.82	1.40	9.24	9.24
		With	15.00	2.00	9.88	1.67	10.26	10.26
	HA	Without	19.72	3.26	19.00	4.38	20.25	20.25
		With	21.00	3.64	21.19	5.46	22.49	22.49
	FA	Without	17.69	2.57	11.22	2.37	11.85	11.85
		With	18.77	2.92	13.01	2.98	13.26	13.26
	HA + FA	Without	25.43	4.87	23.12	5.71	23.80	23.80
		With	28.16	6.24	28.28	7.25	27.41	27.41
	Mean		19.62	3.30	19.53	16.27	3.65	16.81
S3 (11.9 dS m^{-1})	Without	Without	9.70	0.98	7.62	0.77	8.00	8.00
		With	11.50	1.27	8.50	1.02	9.25	9.25
	HA	Without	17.03	2.77	12.64	2.67	13.88	13.88
		With	18.63	3.11	14.82	3.42	15.39	15.39
	FA	Without	14.03	2.20	10.13	1.43	10.65	10.65
		With	15.36	2.43	11.00	1.72	11.70	11.70
	HA + FA	Without	21.17	4.21	19.56	4.68	20.04	20.04
		With	23.55	4.80	23.63	4.55	23.10	23.10
	Mean		16.15	2.63	16.98	13.05	2.33	13.65
LSD 0.05%	A		0.45[a]	0.05[b]	0.52[b]	0.19[b]	0.20[b]	0.05[b]
	B		0.26[a]	0.03[a]	0.32[b]	0.13[b]	0.14[b]	0.14[a]
	C		0.19[a]	0.10[a]	0.21[a]	0.17[b]	0.12[c]	0.12[a]
	ABC		0.21[a]	0.10[a]	0.12[b]	0.02[c]	0.03[b]	0.03[b]

Note: factor of study – A, salinity effects; B, humic substance effects; C, *Moringa* leaf extract effects. *HA* humic acid, *FA* fulvic acid
[a]Significant
[b]High significant
[c]Very high significant

plant growth and nutrient uptake of wheat were obtained with HA application [52, 53]. The addition of humus substances showed anti-stress effects under biotic stress conditions such as unfavorable temperature, pH, salinity, etc. [13]. Potassium humate at a rate of 1.0% treated crop plants showed significantly increase on nutrient accumulation of wheat [50].

Results showed that the application of different humus materials, i.e., HA combined with FA under spraying MLE, gave the highest values of nutrient uptake, i.e., N, P, and K of wheat under soil salinity. An increase in soil salinity commonly results in a reduction of water intake of plants. Passive nutrient uptake of the plants is related to water intake, and any decrease in water availability causes a reduction in the uptake of many plant nutrients. Additionally, the imbalance in the composition of saline soil solution can also cause the uptake of some ions in excessive amounts such as Cl, Na, and Mg. An increase in the concentration of these ions either has a toxic effect directly to the plants or promotes an imbalance in plant nutrient metabolism.

Regarding the effect of soil salinity, data in Table 5 shows that the N-, P-, and K-uptakes by straw and grains were decreased with increasing soil salinity level. This trend was found true under different humic substances with MLE. As mentioned above the plants died off in the control treatment due to extremely high salinity (11.9 dS m^{-1}). Arancon et al. [54] found that increasing salinity stress was associated with significant decreases in NPK accumulation by straw and grains of barley plants. Patit et al. [55] stated the concentration of NPK in wheat plants decreased with increasing salinity stress. Saqib et al. [56] reported that the NPK concentration and its uptake by barley plants decreased with increasing EC.

From statistical analysis, results showed that the foliar spray with MLE under the different soil salinity levels gave a significant increase in straw and grain NPK-uptake of wheat compared to untreated plants "without MLE" (see Table 5). These increases represent 11%, 22%, and 17%, respectively, for straw NPK-uptake and 21%, 15%, and 15% for grain NPK-uptake under salinity stress in the presence of different humus materials. This result is confirmed by Karaman et al., Parida and Das, and Tejera et al. [36, 46, 47]. Salinity also produces ionic stress leading to ionic imbalances and impairment of root membrane selectivity. Abdel-Fattah and Merwad [21] showed that addition of ascorbic acid increased leaves K^+ accumulation under salinity. Addition of MLE and H_2O_2 decreased the concentration of Na^+ and Cl^- along with increased K^+ in leaves against control [57]. Spraying or seed soaking of MLE gave the highest values of shoot and seed NPK content of pea plants under salinity stress [58].

4 Effect of Soil Salinity, Humic Substances on EC, Soil pH, and Available Nutrients

The humic substances are mostly used to remove or decrease the negative effects of chemical fertilizers from the soil and have a major effect on plant growth. Yield and its quality depend upon the availability of micronutrients; in case of polyhouse-grown vegetable, the availability of micronutrients becomes more important, where the source of micronutrients is only an artificial application, and there are more requirements of these nutrients as compared to open-field cultivation. Direct effects of humic compounds to plant development arise from their impacts on root development and nutrient element absorption metabolisms of plants and enriching of nutrient element availability [1]. *Delgado* et al. [51] found that the addition of a liquid mixture of humic and fulvic acids to calcareous soils increased the available phosphorus. The addition of humic acids improved physical, chemical, and biological properties of soil and its impact on nutrient availability [59].

Effect of soil salinity and humic substances with MLE on soil EC, pH, and available N, P, and K in the soils was illustrated in Table 6. With respect to the soil salinity effect, results reveal that the available N, P, and K in the soils were decreased with increasing soil salinity level. This trend was found true under different humic substances with spraying of MLE [22]. On the other hand, results show that soil pH was decreased with the application of humus materials with or without MLE under soil salinity level. Obtained results are similar to those reported by Elgharably [6] and Patit et al. [55] who observed significant negative effects of soil salinity on the availability of N and P in wheat in loam soil. He attributed his results to the inhibitory effects of salinity stress on soil microbial activity and, in turn, on organic N mineralization. The available N, P, and K concentrations in the soils were increased with the

Table 6 Effect of humic substances and foliar spray of *Moringa* leaf extract on EC, soil pH, OM, and available N, P, and K (mg kg^{-1}) under salinity stress at the end of the experiment

Salinity level (A)	Humus materials (B)	EC	pH	OM, g kg^{-1s}	Available N	Available P	Available K
S1 (2.5 dS m^{-1})	Without	2.48	7.87	6.42	35.25	6.25	80.26
	HA	2.16	7.81	6.92	41.92	8.05	89.15
	FA	2.35	7.85	6.75	38.90	7.47	85.36
	HA + FA	2.01	7.51	7.97	45.26	9.98	94.64
	Mean	2.25	7.76	7.02	40.33	7.94	87.35
S2 (6.7 dS m^{-1})	Without	6.32	7.88	6.35	33.74	6.10	75.32
	HA	5.15	7.75	6.71	40.61	7.58	85.61
	FA	5.65	7.80	6.74	35.27	7.30	80.03
	HA + FA	4.87	7.52	7.56	43.67	8.2	90.74
	Mean	5.50	7.74	6.84	38.32	7.30	82.93
S3 (11.9 dS m^{-1})	Without	11.84	7.88	6.15	30.15	6.02	68.74
	HA	10.75	7.80	6.62	36.59	7.32	79.21
	FA	11.01	7.85	6.70	34.02	7.01	74.36
	HA + FA	9.20	7.52	7.32	39.5	8.52	84.39
	Mean	10.70	7.76	6.70	35.07	7.22	76.68
LSD 0.05%	A	0.03	0.17	0.02	0.256	0.12	0.47
	B	0.06	0.05	0.05	0.35	0.17	0.24
	C	0.01	0.04	0.02	0.17	0.10	0.19
	ABC	0.04	0.01	0.04	0.19	0.13	0.23

Note: factor of study – A, salinity effects; B, humic substance effects; C, *Moringa* leaf extract effects. *HA* humic acid, *FA* fulvic acid addition of various humic substances under the salinity levels. These increases represent 20%, 9%, and 29% for available nitrogen; 25%, 18%, and 45% for available phosphorus; and 13%, 6%, and 20% for available potassium under different treatments, respectively. The treatment of HA and FA with or without spraying MLE gave the highest values of available N, P, and K under the salinity levels, while the lowest values were found with untreated soil [15, 22, 49, 50]. Siddhuraju and Becker [60] reported that the application of HA mixed with P fertilizer gave the highest values of water-soluble phosphate, strongly retarded formation of occluded phosphate, and increased P-uptake of plants. The effect of HA and FA on the dissolution of aluminum phosphate and iron phosphate, and assessed their availability to plants. Humic acid was more effective than fulvic acid in dissolving the metal phosphates [61]. The application of HA as soil addition at a rate of 50 mg kg^{-1} combined with phosphate fertilizers gave an increase in organic matter; available N, P, and K; and boron compared to the alone addition of phosphate fertilizers [62].

Soil organic matter contains residues of plants and animals and primary and high polymer organic compounds formed by their decomposition. Soil organic matter has no certain chemical formula due to its dynamic structure. Soil organic matter mainly consists of humic and fulvic acids which are called humin materials. The impacts of HM on soil's physical and chemical properties are shown in Table 6. At the end of the main experiments, soil analyses showed that HM application decreased soil EC values under all tested salinity levels (2.5, 6.7, and 11.9 dS m^{-1}) compared to the untreated controls. In contrast, organic matter was increased in soil treated with HM compared to those in untreated soil. The improving effect of HM was more evident in the mild (2.5 dS m^{-1}) and moderate (6.7 dS m^{-1}) soil salinities than in the severe (11.9 dS m^{-1}) one.

Reclamation of salt-affected soils requires improvements of physical, chemical, and biological properties by applying some means including humus materials (HM) that are intensively used, nowadays, for salt-affected soils in dry regions. Mesut et al. [63] classified the effects of HM on plants under salt stress into indirect and direct effects. The indirect effects of HM are linked to improvements in the physical, chemical, and biological properties of soils, while the direct effects on plants are attributed to improvements of germination, plant growth (root and shoot), and hormone-like activity. Application of HM has increased soil organic matter (OM) content and available contents of the studied nutrients (i.e., N, P, and K). Sarwar et al., Ouni et al., and Rady et al. [64–66] attributed the positive effects of humic acid (HA) on the soil to the increase of OM content and bioavailable nutrients, as a result of a reduction in soil pH. Application of HM to a saline soil encouraged the creation of medium and micropores (i.e., soil water holding capacity and useful pores) of soil particles, in turn, increasing capillary potential. This case is more attributed to an increase in soil moisture content at field capacity and then available water content [67]. *Habashy and Ewees* [68] have reported that OM increases soil microbial biomass density and some soil enzymatic activities such as urease, alkaline phosphatase, and β-glucosidase in the rhizosphere and consequently the reduction in soil pH. It has been also reported that HM (HA and fulvic acid; FA) are known to have high CEC and surface area as compared to soil. This property is considered to have a positive role in nutrient uptake by crops [69]. The increases in water retention in HA-amended soil could help promote microbial growth and sustain root development under moisture stress environment in salt-affected soils [15, 70].

5 Conclusions

The results of this study indicated that application of humus materials as humic and/or fulvic acids under salt stress had a beneficial effect on plant growth, nutrient uptake, and available nutrients. Addition of HA combined with FA with MLE gave the highest values of plant growth, straw and grain yield, biological yield, protein content, NPK-uptake of wheat plants, and available N, P, and K under different soil salinity levels. The lowest values of growth parameters, yield, nutrient uptake, and availability of NPK were obtained with control (untreated soils). Foliar spray of MLE gave an increase of all parameters, i.e., growth, yield, and nutrient uptake in wheat plants compared to untreated plants under soil salinity. More research may be needed to clarify the mechanisms of alleviation done by fulvic and humic acids and their salts.

6 Recommendations

Soil salinization occurs when water-soluble salts accumulate in the soil to a level that impacts on agricultural production, environmental health, and economics. In the early stages, salinity affects the metabolism of soil organisms and reduces soil productivity, but in advanced stages it destroys all vegetation and other organisms living in the soil, consequently transforming the fertile and productive land into barren and decertified lands.

The beginning of the twenty-first century is marked by global scarcity of water resources, environmental pollution, and increased salinization of soil and water. Increasing human population and reduction in land available for cultivation are two threats for agricultural sustainability. Various environmental stresses, viz., high winds, extreme temperatures, soil salinity, drought, and flood, have affected the production and cultivation of agricultural crops; among these soil salinity is one of the most devastating environmental stresses, which causes major reductions in cultivated land area, crop productivity, and quality. It has been estimated that worldwide 20% of total cultivated and 33% of irrigated agricultural lands are afflicted by high salinity. Furthermore, the salinized areas are increasing at a rate of 10% annually for various reasons, including low precipitation, high surface evaporation, weathering of native rocks, irrigation with saline water, and poor cultural practices. It has been estimated that more than 50% of the arable land would be salinized by the year 2050.

An ideal sustainable agricultural system is one which maintains and improves human health, benefits producers and consumers both economically and spiritually, protects the environment, and produces enough food for an increasing world population.

One of the most important constraints to agricultural production in the world is abiotic stress conditions prevailing in the environment.

The problem of soil salinization is a scourge for agricultural productivity worldwide. Crops grown on saline soils suffer on account of high osmotic stress, nutritional disorders and toxicities, poor soil physical conditions, and reduced crop productivity. The present review focuses on the enhancement of productivity under stressed conditions and increased resistance of plants against salinity stress by the application of different humus substances and spraying with moringa leaf extract.

The reclamation of salt-affected soil requires an improvement of physical, chemical, and biological properties. Soil humic substances, such as humic acid and fulvic acid, are mainly derived from the (bio)chemical degradation of plant and animal residues and from microbial synthetic activity, and they constitute a significant fraction of the soil organic matter.

Humic substances are natural organic compounds comprising 50–90% of the organic matter of peat, coal, and sapropel (i.e., sludge that accumulates at the bottom of lakes), as well as of the nonliving organic matter of soil and water ecosystems.

M. oleifera can be used by farmers as a possible supplement or substitute to inorganic fertilizers. *Moringa* leaf extract is rich in amino acids, K, Ca, Fe, and ascorbate, and growth-regulating hormone like zeatin is an ideal plant growth enhancer. Different parts of this plant contain "a profile of important minerals, proteins, vitamins, carotene, amino acids and various phenolics and provide a rich and rare combination of zeatin with several flavonoid pigments. So it is a good source of natural antioxidants" [71].

In addition, several actions of leaf extract were detected by many investigations. The main actions are (a) enhancing the growth of plants and (b) containing higher times of nutrients, amino acids, antioxidants, antiaging, and anti-inflammatory materials, proteins, vitamins, and different minerals [71]. Besides moringa seed cake is used in moringa organic farming and supporting soil microbial growth. *Moringa* plants are drought and salinity resistant that encourages invading desertic sand soils.

There is an increasing interest in the potential use of humic substances as plant growth promoter. Their applications also provide many benefits to agricultural soil, including increased ability to retain moisture, a better nutrient-holding capacity, a better soil structure, and higher levels of microbial activity. The humic acids can significantly reduce water evaporation and increase its use by plants in non-clay, arid, and sandy soils. In addition, humic substances promote the conversion of a number of mineral elements into forms available to plants.

Taking the current leads available, concerted future research is needed in this area, particularly on field evaluation and application of humus substances, i.e., humic and fulvic acids and foliar spray with moringa leaf extract as biofertilizers in the stressed soil. More studies are needed on different crops mainly field crops semi-tolerant to salinity and drought. In these studies, physiological studies are very important to clarify the specific effects of its component.

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Part IV
Integrated Fish, Plant and Animal for Sustainable Food Supply

Importance of Forage Mixtures in Increasing Sustainable Food Supply in Egypt

Hassan Awaad, Nehal El-Naggar, and Hend Hassan

Abstract The cultivation of forage mixtures has an important role in increasing the land use efficiency and utilization of environmental resources. Many farmers resort to forage mixtures to increase the productivity of green forage per unit area. Mixtures are used to increase forage quality and the nutritive value by increasing the proportion of fiber to avoid digestive problems. Cultivation of mixtures improves the mutually beneficial relationship. The most important of these forage mixtures are Sudan grass–cowpea, fodder maize–cowpea, fodder maize–guar, ryegrass–clover, barley–clover, and canary grass–clover, which succeed under Egyptian conditions. The use of nitrogen and phosphorus as fertilizers is also important because of their significant and clear impact on forage yield and quality for livestock.

Keywords Environmental stresses, Forage mixtures, Livestock, Productivity, Quality, Sustainable agriculture

Contents

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1 Introduction

It is well-known that a mixture is produced by mixing the seeds of two or more crop plants to be grown together in the same unit area. Each component contributes to improving productivity, nutritional value, stability, and survival of the mixture. Mixing the fodder plants is an extension of their status in natural pastures. Forage mixtures constitute one of the most important mixed farming systems.

In light of the attitudes toward sustainable agriculture systems and the importance of integration between crop production and the spread of animal production farms, livestock is an important pillar of the national economy in any country and a key element in achieving food security. Livestock development is a key goal to cover the current shortage of animal products because of increased demand. The main reasons for the decline in livestock productivity are limited feed resources, high prices, and the inability to cover feed requirements. Mixtures are therefore required to exploit available environmental resources, increase yield per unit area, and provide a balanced diet for livestock (http://www.alhadeeqa.com/vb/gardens/g8758/).

The advantages of mixtures are that legumes fix atmospheric nitrogen by *Rhizobium* and increase the supply of nitrogen to the grasses and, thereby, protein to livestock. Forage mixtures are, therefore, of higher nutritive value than grass alone. Mixtures offer the longest season for production of palatable grass for animals than pure grasses or legumes [1]. Within the framework of the strategy of sustainable agricultural development for Egypt 2030, Egypt aims to cultivate 22% of the area of Tushka wells, an area of 100,000 fed. [1 fed. (feddan) = 4,200 m^2] with date palm, cultivating the space between them with barley and forage crops. The cultivation of 93% of the South East Low Qattara of 50,000 fed. by winter and summer forage crops and grains for service projects of animal production is also planned. The Eastern

Province of Siwa Oasis, area of 30,000 fed., can be devoted to the cultivation of specialized olive varieties, intercropped with grain and feed crops in suitable crop rotation based on barley and forage crops to cover livestock production activities, especially sheep and goat farming. The area of West Kom Ombo (Plain Gallaba), an area of 300,000 fed., produces oil seeds, pulses, and green and dried fodders integrated with livestock production activities. These crops include corn, beans, and clover and the plant activities are complemented by the establishment of animal activities, including the raising of milk animals as well as centers for milk collection and processing to high specifications and the fattening of calves, together with sheep breeding [2] (www.fao.org/sustainable-development-goals/en/). This trend confirms the importance of forage mixtures in increasing sustainable food supply in Egypt.

2 Types of Forage Mixtures

2.1 Forage Mixtures According to the Method of Utilization of the Resulting Forage

1. Pasture mixtures
2. Mixtures for producing hay
3. Mixtures for producing silage
4. Multi-purpose mixtures

It is interesting to mention that all these mixtures consist of one or more fodder grass mixed with one or more legume crop, but sometimes the mixture consists of fodder grass only, especially when there is no legume suitable for the conditions of the farming area.

2.2 Forage Mixtures According to the Incoming Components of the Resulting Forage

2.2.1 Simple Mixtures

These consist of only two species, one of which is legume and the other is grass, where the quality, quantity, plant composition, and balance of the animal diet can be controlled. Figures 1 and 2 show two examples of these mixtures.

2.2.2 Complex Mixtures

Complex mixtures consist of a group of legume and grass crops and are recommended in the case of short-term periodic pastures and special purpose pastures. It is difficult to control the composition of the mixture after long periods of grazing.

Fig. 1 Mixture of rye grass with Egyptian clover

Fig. 2 Mixture of turnip with Egyptian clover

3 Practical Foundations for Choosing the Mixtures

There are a number of bases and considerations that must be taken into account when choosing two or more forage plants to be grown together in a mixture. The most important of these considerations are the following:

1. They should be suitable for soil conditions and the climate in the area in which they are to be grown
2. They should be suitable for the purpose for which they are to be cultivated, whether for grazing or for drying or silage production
3. They should contain a mixture of at least one legume and one grass

4. The maturation dates of the components should be compatible, ensuring the balanced survival of the grass and legume plants in the mixture throughout production, whether they are annual or perennial crops
5. The degree of competition of plants in the mixture should be compatible so that no component dominates. This means that the mixture must include species compatible in growth. This can be achieved as follows:
   (a) Mixing deep-rooted and shallow-rooted crops
   (b) Varying the nature of growth, such as growing plants with weak climbing stems with plants with strong stems
   (c) Mixing low growing plants with those with erect stems
   (d) Species in the mixtures should be compatible with their maturity dates with regard to the beginning of flowering

4 Mixture Goals

Forage crops are mixed to achieve several objectives, including the following:

1. To reduce the forage moisture, and raise the proportion of dry matter (DM), especially in the first cut
2. To provide access to nutritionally balanced forage
3. To increase the "output" of the unit area vertically, thereby increasing crop area to meet forage shortages or to reduce the area allocated to forage crops and allocating them to strategic crops such as wheat
4. To achieve a balance in the animal feed, especially when mixing clover with some cereal grasses to reduce loss of nutrition, which is estimated to be approximately 40% of the average amount of clover consumed. This amount of forage can therefore be provided in the summer, when it is most needed

5 Advantages of Forage Mixtures

The cultivation of feed mixtures has a number of advantages. Table 1 shows some of the requirements and benefits of mixed cropping systems based on the results of some reference studies, the most important of which are the following:

1. Rationalizing the use of irrigation water, especially in the summer
2. Exploitation of available growth conditions and factors
3. Increasing the return and saving costs
4. Increasing the output of forage yield
5. Increasing the chances of inhibiting the growth of weeds resulting from the intensive vegetative growth of the mixture
6. Reducing the risks of biotic and abiotic stresses

Table 1 Some benefits of the mixtures obtained from the results of some reference studies

Mixture	Increase in yield	Additional forage yield	Improved soil nutrients	Reduced the risks	Increased crop diversity	Improved fodder quality	Reference
Rye grass–Berseem	√	√	√	–	√	√	Ibrahim et al. [3] and Salama and Badry [4]
(Oats, barley or wheat)–vetch	√	√	√	√	√	√	Ansar et al. [5]
Barley–berseem	√	√	–	√	√	√	Aly [6]
(Rye or canary grass)–berseem	√	√	√	√	√	√	Geweifel [7]
Oats–legumes	√	√	√	√	√	√	Kaiser et al. [8]
Meadow fescue–white clover	√	√	√	√	√	√	Harasim [9]
Meadow fescue–clover	√	√	√	√	√	√	Erkovan et al. [10]
Fodder maize–cowpea, guar	√	√	√	√	√	√	Hassan Hend [11]
Sudan grass–cowpea	√	√	√	–	√	√	Abd El-Gawad et al. [12, 13]
Pearl millet –cowpea	√	√	–	–	√	√	Hassan Hend et al. [14]
Barley–lentils	√	√	√	–	√	√	Schmidtke et al. [15]
(Barley, rye, or canary grass)–berseem	√	√	√	√	√	√	Aly [16]
Cereal grass–faba bean	–	–	–	√	√	√	Fernández-Aparicio et al. [17]

7. Improving the degree of palatability to animals of the forage mixture rather than the single crop
8. Reducing the chances of animals bloating
9. Ensuring the provision of forage for longer periods of the season
10. Increasing nitrogen and organic matter content of soil
11. Improving both carbon:nitrogen ratio (C:N ratio) and degradation rate of organic matter

6 Reasons for Using Forage Mixtures

The symbiotic relationship between the legume plant with *Rhizobium* in atmospheric nitrogen fixation and the utilization of the grass component, this leads to an increase in the average content of protein mixture and reduces the need for chemical fertilizers in sustainable agriculture. The perennial legumes have great potential for increasing sustainability in grassland systems. Rates of N_2 fixation estimated in plant tissues above soil surface were 350 kg N/ha/year in alfalfa and 373 kg N/ha/year in red clover, reaching 545 kg N/ha/year in white clover. Therefore, when these species are grown in mixtures with cereal grass, they take a significant amount of the nitrogen required from biological nitrogen fixation – about 80% [18].

It was observed that the roots of the intercropped crops interfere with each other, leading to complementary interactions between the root systems in nitrogen transport and the integration of different nutrient use [19].

Current nitrogen transition from the legume to the associated grass component during the season has been associated with earliness. Early maturity legumes improve nitrogen nutrition and increase the yield of associated grass whereas late-maturity legumes produce this effect on the non-legume crop, which is followed in the crop rotation. Overall, studies have shown that the transfer of nitrogen from legume crop to grass occurs at a distance of at least 20 cm, and the maximum occurs when the ratio of legumes:grass is greater than 1:1 [20].

It has been shown that the percentage of nitrogen moving from legume to grass increases at the end of the legume life and earlier than grass. Transfer of nitrogen from legume to grass occurs in two ways: first, directly from legume to grass through the soil and, second, through animals that graze via their urine and dung. The second way is less important than the first because urine and animal droppings affect a small part of the soil surface [21].

Cultivation of cereal grass with a legume increases the production of grass compared to a single legume and therefore increases intake from the forage and the acquired weight of the animal. It is interesting to note that cultivating bromegrass and red fescue in mixtures with alfalfa leads to homogenous production and constant levels of feed throughout the season [22].

Integration and facilitation between the two components of the mixture to utilize the available resources leads to improvement of forage quality and quantity through the complementary effects of two crops grown on the same area and net income relative to the pure stands [11] simultaneously.

Mixtures provide better disease control as the resistant component works as physical barriers to spore dispersal [17]. Mixtures of oats with berseem give an early cut and protect the young berseem seedlings against cold stress condition (www.fao.org/ag/agp/agpc/doc/bulletin/winterfodder/potential.pdf).

7 Role of Mixtures in Improving Productivity and Quality of Forage

Mixed cereal crops, such as fodder maize, are combined with annual legume crops, which not only increase the yield of the dry matter crop but also improve feed quality. For example, the concentration of crude protein increased from 19 to 27 g/kg and the crude protein yield per hectare from 13.0 to 37.8% compared to individual maize [23]. Examples of feed mixtures include the following.

7.1 Forage Mixture of Millet, Sudan Grass, and Cowpea

It is possible to cultivate summer legumes such as fodder cowpea and guar with millet and Sudan grass, where the mixture is given a vegetable yield higher than the single grass. In addition, the mixture provides a balanced diet (carbohydrates derived from the grass and protein from the legume) together with soil-improving properties.

Under Kafr Al-Hamam Agricultural Research Station, Egypt, Hassan Hend et al. [14] investigated six species of grasses with legume summer forages. They registered the superiority of the pearl millet–cowpea cropping pattern over other pure stands and cropping systems, with totally fresh and dry forage yields valued at 32.51 and 6.50 tons/fed. and total crude protein yield of 766.56 kg/fed.

In this field, Abd El-Gawad et al. [12] studied the levels of organic fertilizer (zero, 20 m^3/fed.), nitrogen (0, 67.5, 135 kg N/P), and mixed intercropping systems (1:0, 1:1, 1:2, 1:3, 2:1, 3:1, and 0:1) for hills of fodder cowpea Esmerala cv. and the Sudan grass Qena cv., respectively, planted on alternate hills on one side of the ridge at a distance of 20 cm under conditions of calcareous land at the Mariout Research Station Farm, Egypt. The results indicated the superiority of the fresh and dry yield of each fodder cowpea and Sudan grass and their mixture in response to the effect of organic fertilizer at 20 m^3/fed. and nitrogen fertilization with 67.5 and 135 kg N/P. The dry yield of the fodder cowpea was also higher in the 2:1 system. The fresh and dry yield of Sudan grass and their mixture was superior under the 1:3 mixing system. Percentage of leaf:stems dry weight in fodder cowpea responded to increase organic fertilization in the first and second cuts. A significant increase was also registered in the ratio of the ability to convert solar energy to chemical energy in the second cut.

To complement these results of forage quality, Abd El-Gawad et al. [13] found that the application of mixing systems led to an increase in the total carbohydrates and crud fiber in the three cuttings, the percentage of crud protein in the second and third cuts, and ash in the first cut. Crude protein, total carbohydrate, crud fiber, and ash for fodder cowpea increased with different mixing systems. For the Sudan grass, the application of different mixing systems was accompanied by an increase in the percentage of crude protein, crud fiber, and ash in the three cuts, and total carbohydrates in the second cut.

Different proportions of a mixture of fodder cowpea–Sudan grass was investigated in the valley of Quachila, California by Wang and Nolte [24]. They found that the mixture of fodder cowpea–Sudan grass of 75 + 25% gave the best results. It produced 1.5 tons/acre from fodder cowpea and 2.7 tons/acre from the biomass in 2 months. This mixture achieved the best ratio of carbon:nitrogen and improved the efficiency of atmospheric nitrogen fixation by cowpea in the mixture, although interspecific competition between the two components of the system decreased.

7.2 Forage Mixture of Maize, Cowpea, and Guar

An extended experimental study at the Faculty of Agriculture, Zagazig University, Egypt demonstrated the effect of different mixing systems for three green forage crops – fodder maize, fodder cowpea, and guar – on productivity and quality as shown in Tables 2 and 3. Hassan Hend [11] found that the mixture fodder maize 100% + guar 50%, all on two sides of the ridge, alternately give the highest percentage of leaves, and stems and maximum fresh yield (17.9 tons/fed.) when compared to other forage mixtures or solids, with a land equivalent ratio LER of 1.34. This means a yield advantage of 34%. The delay of cutting from 56 to 66 days from sowing led to an increase in the fresh and dry forage yield. This has been discussed based on a prolonged growth period and the expansion of photosynthetic activity. A mixture of fodder maize 100% + 50% cowpea produced the highest total of digestible nutrient (TDN)/fed. followed by the mixture fodder maize 75% + guar 50%, all on two sides of the ridge. Alternately, the delay of cutting from 56 to 66 days from sowing increased the yield of both protein and total digestible nutrient (TDN).

7.3 Forage Mixture of Barley or Wheat with Lentils

It can be said that, under sustainable agriculture conditions, high nitrogen efficiency can be achieved by mixing cereal crops with lentils to increase the efficiency of nitrogen fixation without reducing the efficiency of soil nitrogen absorption.

Table 2 Dry and fresh yield (ton/fed.) for fodder maize, cowpea, and guar, and its effect by mixing systems and cutting date, and the percentage of land equivalent (LER) based on dry fodder yield/fed. [11]

Main effects and interactions	Total fresh yield (ton/fed.)			Total dry yield (ton/fed.)			LER
	First season (2001)	Second season (2002)	Comb. data	First season (2001)	Second season (2002)	Comb. data	Comb. data
Mixture pattern (M):							
1. Fodder maize (100%)	19.678c	12.718a	16.198b	4.083c	2.833a	3.458b	–
2. Cowpea (100%)	15.022e	9.001d	12.012e	2.681e	1.383e	2.082g	–
3. Guar (100%)	10.397h	6.637f	8.517h	1.799g	1.052f	1.425h	–
4. Fodder maize (50%) + cowpea (50%)	13.392f	9.198d	11.295f	2.620e	2.259bc	2.439e	0.867c
5. Fodder maize (50%) + guar (50%)	12.436g	7.564e	10.000g	2.468f	1.826d	2.147f	0.775f
6. Fodder maize (75%) + cowpea (50%)	21.768b	10.867b	16.317b	4.271b	2.427b	3.349bc	1.145c
7. Fodder maize (75%) + guar (50%)	17.554d	9.866c	13.710d	3.615d	2.102c	2.859d	1.054d
8. Fodder maize (100%) + cowpea (50%)	22.850a	12.973a	17.911a	4.924a	2.842a	3.883a	1.337a
9. Fodder maize (100%) + guar (50%)	19.211c	11.034b	15.122c	4.200b	2.443b	3.321c	1.225b
F-test	**	**	**	**	**	**	**
Cutting date (C):							
56 days after sowing	15.367b	8.742b	12.055b	2.963b	1.760b	2.361b	1.083b
66 days after sowing	18.479a	11.226a	14.853a	3.851a	2.499a	3.175a	1.051b
F-test	**	**	**	**	**	**	**
Interactions:							
M × C	**	N.S.	**	**	**	**	**

The terms a ... h in this table are the letters resulting from the statistical analysis indicating that there are significant differences between the treatments of this table The letter a, refers to the treatment with the highest value and the letter h indicates the treatment with the lowest value Different values in the letter, indicating the existence of a significant difference between them The similar values in the letters, indicate that there is no statistically significant difference between them

N.S. not significant

**Significance at 0.01 level of probability

Table 3 Total protein yield (ton/fed.) and total digestible nutrient (TDN) (ton/fed.) for fodder maize, cowpea, and guar, and influenced by mixing systems and cutting date [11]

Main effects and interactions	Total protein yield (ton/fed.)			Total TDN yield (ton/fed.)		
	First season (2001)	Second season (2002)	Comb. data	First season (2001)	Second season (2002)	Comb. data
Mixture pattern (M):						
1 Fodder maize (100%)	0.372cd	0.223	0.293de	2.631c	1.518a	2.074b
2 Cowpea (100%)	0.713a	0.232	0.472a	2.322d	0.905bc	1.613d
3 Guar (100%)	0.402c	0.162	0.282de	1.366g	0.733c	1.050f
4 Fodder maize (50%) + Cowpea (50%)	0.402c	0.225	0.313cde	1.980e	1.209ab	1.594d
5 Fodder maize (50%) + Guar (50%)	0.302d	0.185	0.313cde	1.719f	0.963bc	1.341c
6 Fodder maize (75%) + Guar (50%)	0.625ab	0.241	0.244e	3.127b	1.388a	2.257b
7 Fodder maize (50%) + Guar (50%)	0.442c	0.229	0.433ab	2.463d	1.164ab	1.813c
8 Fodder maize (100%) + Cowpea (50%)	0.632ab	0.222	0.335cd	3.480a	1.535a	2.507a
9 Fodder maize (100%) + Guar (50%)	0.548b	0.199	0.427ab	2.973b	1.240ab	2.107b
F-test	**	N.S.	**	**	**	**
Cutting date (C):						
56 days after sowing	0.430b	0.191b	0.310b	2.155b	1.063b	1.609b
66 days after sowing	0.556a	0.235a	0.396a	2.747a	1.305a	2.026a
F-test	**	**	**	**	**	**
Interaction:						
M × C	N.S.	N.S.	N.S.	*	N.S.	N.S.

The terms a ... g in this table are the letters resulting from the statistical analysis indicating that there are significant differences between the treatments of this table The letter a, refers to the treatment with the highest value and the letter g indicates the treatment with the lowest value Different values in the letter, indicating the existence of a significant difference between them The similar values in the letters, indicate that there is no statistically significant difference between them

N.S. not significant

*Significance at 0.05 level of probability

**Significance at 0.01 level of probability

Because of the solid cultivation of lentils, barley or wheat do not fully utilize the land and available resources (soil and light elements), whereas mixed cropping increases the efficiency of available resources and improves the integration of the use of growth factors in a manner that reduces competition to the growth environment. Cu et al. [25] growed wheat and white lupins either in mixed culture or in monoculture. They found that root dry weight, shoot phosphorus concentration, and

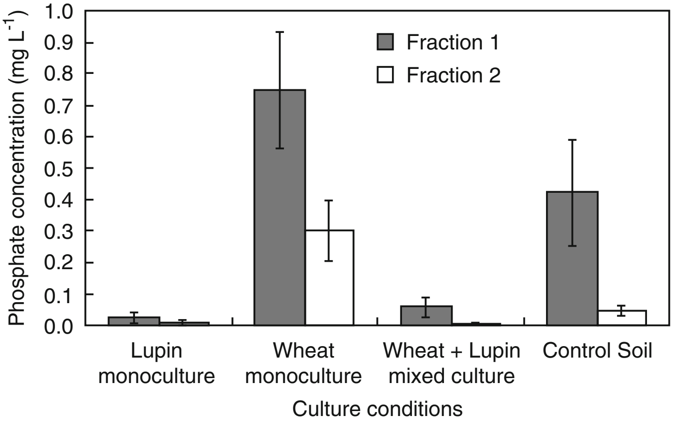

Fig. 3 Effect of plant growth on the concentration of citric acid-leachable phosphate in the soil [25]

root phosphorus concentration were significantly higher for lupin compared to wheat. Mixture cropping significantly improved both shoot growth and shoot phosphorus concentration of wheat, but did not in lupins. Hereby, lupins in mixture cropping continued to obtain an adequate supply of phosphorus, and the supply of phosphorus to the wheat was enhanced. Lupins growing under low phosphorus environment are found to exude large amounts of organic acid anions such as citrate and protons from their roots, and this led to improving their phosphorus nutrition (see Fig. 3).

Schmidtke et al. [15] studied three different morphological varieties of lentils and a class of naked spring barley as single cultivars and in a substitutive mixture for 2 years. Barley–lentils mixtures achieved a yield advantage for two reasons. The first was the higher crop growth rate of the barley in the early growth stage resulting from the high use efficiency of low soil nitrogen. The second is attributed to the improving growth rate (CGR) of lentils as a result of their fixed atmospheric nitrogen. Nitrogen fixation level was 154/117 kg N/ha in the 2001/2002 season in solid lentils and 95/41 kg N/ha in mixed intercropped lentils. The amount of nitrogen taken from the soil was 58/61 kg N/ha in the 2001/2002 season and 17/8 kg N/ha in solid agriculture and intercropped lentils, respectively. Solid lentils raised the level of soil nitrogen in the 60-cm layer, showing a significant effect of nitrogen on crop yield. At the end of the single lentils harvest, it leaves 52 kg N/ha in the soil in the lentils–barley cropping system. The harvest indices for dry matter and nitrogen have increased in the following order: single lentils $<$ mixture $>$ single barley, whereas the nitrogen balance in the two components of the system has taken a reverse direction.

8 Food Mixtures of Cereal Grasses with Egyptian Clover

Abdoul Galil [26] stated that, with limited land resources (8.7 million fed.), water (55.5 million m^3), and small agricultural ownership (90% owned less than 5 fed.), taking into account the cropping system and crop rotation in Egypt, Egyptian clover occupies more than one-third of the area cultivated during the winter season (wheat growing season). Therefore, most of the increase in wheat area is expected to be at the expense of the area given to Egyptian clover.

Mixing cereal grasses with legume crops improves fodder yield and quality. A variety of berseem species were mixed with a number of annual cereals grasses (oats, barley, and wheat). The yield of the fodder mixture was increased compared to pure stand. Protein content, crud fiber, ash, and then total digestible nutrients are also improved.

8.1 Effect of Mixing Grasses with Egyptian Clover and Other Legumes on Forage Yield

Egyptian clover remains the main forage crop in Egypt during winter and spring; increasing forage production can be achieved by mixing the clover with grain grasses. This also increases the forage yield and reduces animal inflation injury with the equilibrium of protein and fiber.

Oats are an important winter cereal fodder grown widely for forage production. It can be cut and fed to animals or can be grazed. It can also be preserved in the form of hay or silage. According to Picasso et al. [27], many previous studies confirmed that advantages can be obtained from forage mixtures and mixing Egyptian clover with ryegrass, oats, or barely compared to sole crops, both in fresh and dry fodder yield as well as quality and better distribution of fresh fodder yield through different cuttings.

When Ansar et al. [5] evaluated yield and quality of oats, barley, and wheat as sole crops and their mixtures with vetch in pattern 50:50, the oats–vetch mixture showed a good average performance under rainfall in increasing fodder fresh and dry yields 20% more than pure oats. Oats–vetch mixture increased dry matter yield by 63% and 78% more than barley–vetch and wheat–vetch, respectively. Cereals–vetch mixtures also gave higher protein content than a pure stand of each.

Likewise, in Egypt, Helmy et al. [28] studied the effect of mixing ryegrass and barley (cv. Giza 123 and Giza 2000) with Egyptian clover. It was concluded that fresh forage, dry forage, and dry matter yields of ryegrass and barley with Egyptian clover mixtures were superior to their pure stands. The dry matter yield of barley cv. Giza 123–Egyptian clover mixture was higher than other cropping systems including barley cv. Giza 2000–Egyptian clover, ryegrass–Egyptian clover, and Egyptian clover pure stand by 14.2%, 5.7%, and 16.1%, respectively. Furthermore, Ibrahim [29] studied the effect of mixing ryegrass 25% with Egyptian clover 75% and 100%

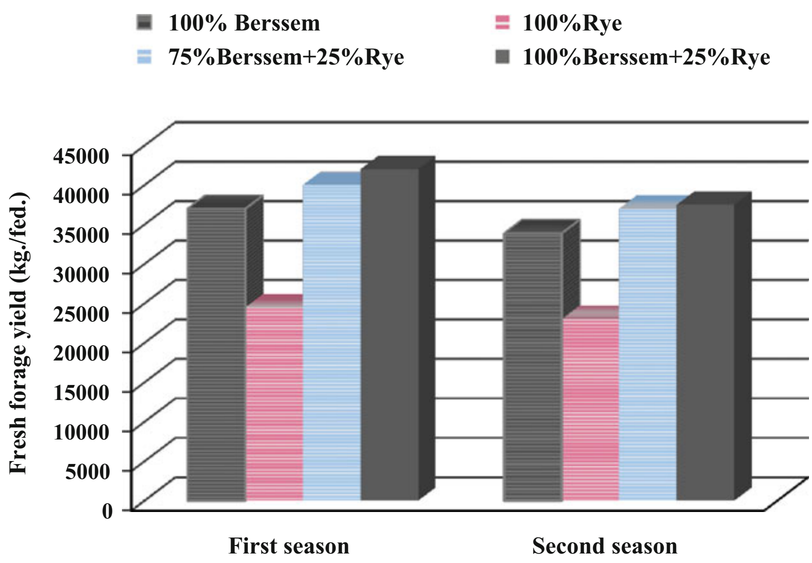

Fig. 4 Seasonal fresh forage yield as affected by mixing treatments [29]

compared to pure stand under two nitrogen levels (0 and 30 kg N/fed.) and three phosphorus levels (0, 23, and 46 kg P_2O_5/fed.). Sole ryegrass yield decreased as comparison to ryegrass yield when mixed with Egyptian clover. Sole ryegrass yield was less than sole clover and mixture of ryegrass–clover yields, except for the first cutting in the second season. Moreover, most of the clover cuttings under 75% produced a higher yield than 100%, where the plant was able to compensate for the low quality and proportion by increasing growth strength by considering efficiency of space and growth factors. The seasonal forage yield/fed. of mixture treatment was superior to the seasonal yield for both sole clover and sole ryegrass (see Fig. 4). The increment in the seasonal yield resulted from the increase of total yield of the three cuttings in the first season and for the second cutting in the second season. Furthermore, the growth of ryegrass with clover did not affect the growth and yield of clover under the mixed-intercropping system. The average performance of clover was the same in the mixture and the individual agriculture. Sole yield of clover was not significantly different from mixture yield, indicating that the ryegrass could not resist the aggression of the clover.

Salama [30] investigated the effect of mixing rate on the yield of Egyptian clover intercropped with ryegrass under three organic fertilizer treatments (control, compost, and poultry litter). The results revealed that the mixtures 70% clover +30% ryegrass followed by 50% clover +50% ryegrass were superior to other treatments in first cutting fresh and dry forage yield, which were 10.22 and 9.45 tons/ha, respectively. Sole legumes yield was better than sole grass yield. Sole ryegrass produced higher DM content, particularly under compost and poultry litter fertilizers, being 200.04 and 175.85 g/kg, respectively.

8.2 Effect of Mixing Grasses with Egyptian Clover and Other Legumes on Forage Quality and Nutritive Value

The effect of mixing oats with legumes and ryegrass with legumes on forage yield and quality was studied by Kaiser et al. [8]. They stated that solid clover was superior to the oats–clover mixture in nitrogen content, solid oats produced the lowest nitrogen content, and the opposite occurred for soluble carbohydrate content.

Mixing clover with barley (6 kg + 37.5 kg/fed.) produced the highest carbohydrate content followed by sole barley. Reducing barley in the mixture from 37.5 to 25 and 12.5 kg led to a reduction in carbohydrate content in forage mixture, and sole clover gave the lowest carbohydrate content. In contrast, sole clover produced the highest protein content, which decreased with decreasing clover in the mixture from 18 to 12 and 6 kg at 60 and 100 DAS [31].

Similarly, Salama and Badry [4] investigated the effect of mixing rates on fodder quality of Egyptian clover (EC) and ryegrass (RG). They reported that sole RG as well as a 70% EC + 30% RG mixture produced the highest carbohydrate content of 273.00 and 266.78 g/kg, respectively, in comparison to other treatments. In contrast, and as expected, sole EC gave the highest protein content of 155.52 g/kg followed by 70% EC + 30% RG treatment of 132.82 g/kg. Concerning fiber fractions, the results stated that sole RG and 30% EC + 70% RG were superior in neutral detergent fiber (505.74 and 523.90 g/kg), respectively, and sole RG produced the highest acid detergent fiber. On the other hand, sole EC and a 70% EC + 30% RG mixture gave the highest acid detergent lignin at 23.68 and 23.55 g/kg, respectively.

At the same time, Thalooth et al. [32] studied the effect of mixing Egyptian clover (EC) with ryegrass (RG) and of different sources of fertilizers on their yield and quality. They reported that sole EC produced the highest crude protein followed by mixing treatment (75% EC + 25% RG). They revealed that a 75% EC + 25% RG mixture was superior in crude fiber content, digestible crude protein, and total digestible nutrient yield in the third cutting under the combination of (Bio + Org. + Chem.) fertilizer treatment in comparison to the other mixing treatments.

8.3 Effect of Mixing Grasses with Egyptian Clover and Other Forage Legumes on Botanical Composition

Under Egyptian conditions, Egyptian clover, which stands continuous cutting or grazing, is the most widespread and well-adapted. The results related to the growth response of each component and botanical composition of non-legume mixtures with clover was varied. Aly [16] in his study on mixtures of fodder grasses (barley, canary, and ryegrass) with clover, explained the differences in the contribution of the grass species to dry matter production during the different cuttings. The contribution of barley and ryegrass was superior in forage yield to canary grass by the first cutting, and the contribution of ryegrass was higher in forage yield than canary and barley with the second and third cuttings. The clover confirmed higher competition with the associated crops except for barley during the first cutting, the latter being the most competitive.

To complete his studies on the forage mixtures, Aly [6] investigated the effect of mixing barley cv. Giza 124 with Egyptian clover cv. Sakha 3 under sandy soil conditions in the experimental farm Khatara, Faculty of Agriculture, Zagazig University. The results showed a positive response of grain component to the addition of nitrogen fertilizer up to 20 kg N/fed./cutting, through the first and second cuttings. In contrast, there was a negative response of legume component to the addition of nitrogen fertilizer. The proportion of barley component contribution to the forage yield in the clover–barley mixture has also decreased from the first to the second cutting and disappeared in the third cutting, giving the clover component an opportunity to increase as the growing season progresses. The contribution proportion of the barley component in forage dry yield for clover–barley mixture was increased in the first cutting with an increment of nitrogen from 0 to 10 and 20 kg/fed./cutting. Based on the results of the first cutting, barley was the dominant component, where barley became stronger with the increase of nitrogen.

To investigate the mutual effect of mixed intercropping ryegrass with clover under conditions of availability of water and food to both components, Harold and Barnes [33] observed that clover growth reduced by 30% because of intercropping with ryegrass, and this effect varied slightly as clover density increased. The existence of clover has reduced the yield of ryegrass in proportion to the increased density of the latter.

8.4 *Effect of Nitrogen and Phosphorus Fertilization on Forage Yield of Grass–Egyptian Clover Mixtures*

Studying the effect of phosphorus fertilizers and phosphorus-solubilizing bacteria on clover and its mixtures with ryegrass, Erkovan et al. [10] found that increasing phosphorus from 0 to 11, 22, 33, and 44 kg/ha had a significant effect on ryegrass dry matter and botanical composition, which led to an increase in dry matter production.

Nitrogen addition may decrease clover yield as well as reduce its contribution to grass–clover mixture yield. However, it increases total forage yield of the mixture, attributed to the effect of nitrogen fertilization on symbiotic fixation of legume components. Ibrahim [29] confirmed that applying nitrogen at 30 kg N/fed. had no significant effect on forage fresh and dry yield of clover, although it increased forage yield of ryegrass, resulting in an increment in total and seasonal forage yields/fed. (Table 4). He also revealed that yield responded positively to phosphorus addition. Whereas each increase in phosphorus levels resulted in a

Table 4 Seasonal fresh fodder yield (tons/fed.) as affected by mixing treatments (M) and nitrogen fertilization (N) during 2010/2011 [29]

Mixing treatments	Nitrogen level (kg N/fed.)		Difference %
	0	30	
M_1 Berseem	B 32.629c	A 34.11b	+ 4.5
M_2 Rye	B 21.598d	A 24.630c	+ 14.0
M_3 75% + 25%	B 35.730b	A 37.232a	+ 4.2
M_4 100% + 25%	A 37.987a	A 37.539a	_

Values with the same letter, denote no significant difference
Values with different letters, denote a significant difference

Table 5 Seasonal fresh fodder yield (ton/fed.) as affected by mixing treatments (M) and phosphorus fertilization (P) during 2009/2010 [29]

Mixing treatments	phosphorus level (kg P_2O_5) Response equation				
	0	23	46	Y max (ton/fed.)	X max (kg P_2O_5)
M_1 Berseem	C 3.091c	B 3.313b	A 3.772c	3.091	0.46 × +
M_2 Rye	C 2.752d	B 3.021c	A 3.227d	2.752	0.24 × +
M_3 75% + 25%	C 4.356a	B 4.602a	A 5.138b	4.358	0.39 × +
M_4 100% + 25%	C 4.052b	B 4.703a	A 5.837a	4.052	0.67 × +

Values with the same letter, denote no significant difference
Values with different letters, denote a significant difference

significant increase in forage fresh and dry yield of clover but had less impact on ryegrass, the total and seasonal yield increased (Table 5). El-Karamany et al. [31] explained that the addition of nitrogen at 60 kg N/fed. to clover + barley mixtures has produced the highest yield of forage 20.48 tons/fed., compared to other treatments where the rate of 30 kg N/fed. was in second place 45 kg N/fed. was last.

8.5 *Effect of Nitrogen and Phosphorus Fertilization on Forage Quality of Grass–Egyptian Clover Mixtures*

Addition of nitrogen resulted in a significant increase in crude protein and fiber content, as well as total digestible nutrient yield (TDNY) for clover and ryegrass in all cuttings except first and fourth cuttings of clover during both seasons of study. Furthermore, adding the first dose of phosphorus (23 kg P_2O_5/fed.) led to a significant increase in (TDNY) of ryegrass [29].

Study of nitrogen fertilization effect on quality of fodder yield of clover and ryegrass has been accomplished in many research studies. El-Karamany et al. [31] found that applying 60 kg N/fed. gave the highest carbohydrate content amounting to 20.16% followed by 45 and 30 kg N/fed. which yielded 19.94% and 19.52%, respectively, at 60 DAS, whereas at 100 DAS the level of 60 kg was the highest followed by 30 and 45 kg N/fed. Crude protein also gradually increased by increasing N levels from 30 to 45 and 60 kg N/fed. either at 60 or 100 DAS.

Salama and Badry [4] indicated that forage crude protein CP increased from 121.73 to 133.93 g/kg with increasing nitrogen fertilization level from 72 to 143 kg N/ha, whereas the addition of nitrogen had no significant effect on carbohydrate or fiber fractions. At the same time, Thalooth et al. [32] pointed out that the increment of crude protein content under different sources of nitrogen fertilizers (bio, organic, and chemical) may be because of the increase of available nitrogen concentration around the roots.

9 Role of Mixtures in Tolerate Environmental Stresses

The variation between the species of fodder mixtures in their tolerance to biotic and abiotic stresses helps to avoid the risks and achieve crop advantage. In this concern, Eskandari [34] indicated that growing cereals with legumes is important for the development of sustainable food production, especially with limited inputs. This could be because of the reduction of risks from pests, root parasite diseases, and weeds.

Mundt et al. [35] grew five winter wheat cultivars, six two-component cultivar mixtures, and one four-way mixture in the presence of yellow rust, eyespot, both diseases, and neither disease for three seasons. Mixtures reduced the disease severity of yellow rust relative to the component pure stands by 53%. The four-component mixture provided better yellow rust control than did the two-way mixtures. Eyespot severity was also reduced through mixing in the absence of yellow rust and by three of the seven mixtures (reduction = 13%). They added that the mixtures achieved yield increases relative to the pure stands of 6.2%, 1.7%, 7.1%, and 1.3% in the presence of yellow rust, eyespot, both diseases, and neither disease, respectively.

Mixed intercropping can play an important role in controlling chocolate spot incited by *Botrytis faba*. Fernández-Aparicio et al. [17] investigated the effect of intercropping on chocolate spot severity in field experiments performed in Egypt, the Palestinian Territories, Spain, and Tunisia. Susceptible faba bean cultivar was grown as a single or with two mixed species intercrops of barley, oats, triticale, wheat, pea or common vetch, or with three mixed species intercrops of wheat and berseem clover. Chocolate spot infection was significantly decreased when faba beans were intercropped with cereals, but not when intercropped with legumes. The repression of chocolate spot infection can be related to a combination of low biomass host, change plant microenvironment, and physical barriers to spore dispersal.

On the other hand, oats grown in mixture with berseem give an early cut as well as protect the young berseem seedlings during cold weather. There are higher fodder yields than other winter cereals such as wheat and barley. Similarly, mixture is more palatable than wheat and barley because of the high number of leaves and soft stems (www.fao.org/ag/agp/agpc/doc/bulletin/winterfodder/potential.pdf).

10 Conclusion

It is known that Egypt suffers from a shortage in production of forage crops, which is widening the gap between production and consumption by livestock. Despite the great importance of Egyptian clover as the first green forage crop in Egypt, the low level of fiber, especially in the first cutting, leads to digestive disorders of animals. Here is the reason for a grass–clover mixture, as the grass component contributes to increased fiber and thus avoids this problem. The most important of these forage mixtures are Sudan grass–cowpea, fodder maize–cowpea, fodder maize–guar, ryegrass–clover, barley–clover, and canary grass–clover, which succeed under Egyptian conditions.

Forage mixtures increase their productivity compared with the pure stand of each component. they also increase the quality of fresh or dry forage yield regarding protein and fiber fractions. Likewise their effect on plant growth performance and botanical composition.

Both nitrogen and phosphorus fertilization have a role in increasing the productivity and quality of forage mixtures. The role of nitrogen was more pronounced in increasing the forage yield of the grass component and increasing the total digestible nitrogen yield of clover with the negative effect on nitrogen symbiotic fixation. Otherwise, it did not have a clear effect on carbohydrate content. Phosphorus fertilization had a positive role in increasing forage yield of clover and its quality, and increasing the TDNY of the grass component.

11 Recommendations

In light of the above, the following recommendations can be made:

– Use the forage mixtures as one of the farming methods to increase productivity and quality of forage and overcome the shortage in production of forage crops
– Select the most suitable crop cultivars that maximize utilization of available environmental resources and increase the output of forage mixture
– Expand the cultivation of forage mixture patterns including cereal grass and legume crops such as Sudan grass–cowpea, fodder maize–cowpea, fodder maize–guar, ryegrass–clover, barley–clover, and canary grass–clover.

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Algae and Chain Aquaculture: An Approach Towards Sustainable Agriculture

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Abstract Global warming, water scarcity and the rise of sea level have resulted in drastic changes that lead to shortage of living resources needed to meet the demands of the ever-increasing human population. Moreover, the contaminated and the poor quality of resources available represent challenges for any sustainable development plans. The major challenges that hinder the establishment of sustainable agriculture are the limited water resources, the limited fertilizer supply and the limited hospitable space (where edible food and water exist) for placing the population. Also, eco-friendly solutions that are not hazardous or polluting are needed to suffice the living and space demands of the increasing population. In Egypt, the population is mainly centred in the delta area and the narrow fertile Nile valley. This is uneven demographic distribution as most of Egypt's area is uninhabited deserts. Desert lands that represent more than 95% of the total area of Egypt can provide a solution for the lack of hospitable space and establishing new sustainable communities. The present chapter discusses a proposed working model in which algae play major roles. Algae, the photosynthetic plantlike organisms, are important part of the different global ecosystems. Nevertheless, they have been underexploited in case of agriculture despite their indispensable role as primary producers and as a rich source of nutrients and bioactive compounds as well. Our model is based on using innovative strategy of integrating the culturing of algae, fish and plants in a sustainable aquatic chain. The unpolluted underground water, which is mostly brackish, provides a solution to the limited water resources and is to be used for establishing algal and fish cultures. Algae are to be used as fish feed in part and as biofertilizers for plants. The algae are to be mass cultured using an economic open culturing pond/system. Meanwhile, the fish wastewater would be reused for the irrigation of plants where the phosphorus,

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nitrogen and organic matter in the wastewater represent natural fertilizers for plants. The plants are also to be biofertilized using algal bioconcentrate/biomass. This integrated system in which algae play multiple roles would hopefully offer solutions to obstacles hindering sustainable agriculture.

Keyword Algae, Aquaculture, Biofertilizers, Fish feed, Underground water

Contents

1 Introduction

The increased sea level and the salinization of agricultural land plots are two major concerns that face Egypt nowadays [1, 2]. New land plots have to be reclaimed that are not under the danger of increased sea level. As most of Egypt's area is desert land, vast areas can be cultivated using underground water. The underground water reservoir of Egypt is, as well-known, vast. "Egypt has an underground water reserve that could last hundred years" [3].

The underground water offers a suitable alternative for irrigation with Nile water, despite being in several instances saline, as it can be utilized for integrated agriculture, e.g. irrigation of agricultural crops combined with fish culture. It is a fact that agricultural land plots of Nile Delta and Nile valley are deteriorating due to decades of land abuse, heavy application of insecticides, growth regulators and harmful manufactured fertilizers that lead to the contamination of crops and soils with toxic chemicals. Therefore, unconventional methods of reclaiming new lands and turning them into food productive plots are needed. Currently, there is a lack of good-quality food supplies, and this shortage extends to fish supply as massive fish mortalities, due to pollution and contamination of Nile water with toxic wastes, are reported [4].

Establishment of fisheries in desert areas and recycling the wastewater of those fisheries to cultivate plants represent a chain aquaculture which seems to be the most plausible solution for problems such as pollution and limited water resources [5]. Inland saline aquaculture has been successful in Negev desert where growing fish in deserts using saline or brackish underground water offers a year-round production of fish, a suitable temperature for growing fish using geothermal water, natural barriers against pathogens and pollution as well as maximum water economy [6]. Algae can also be grown on that type of water to serve multiple purposes such as fish feed [7], biofertilizers and soil conditioners [8]. Concomitantly, algae play a central role in integrated chain aquaculture by starting the chain through adding algae to fish feed as well as its roles in biofertilization and soil stabilization.

Moreover, integrated aquaculture-agriculture would offer natural fertilizers derived from the wastewater recycled from fish culture [9] including phosphorus, nitrogen and organic matter [10]. Overall, this integrated system offers solutions to pollution, limited resources and water scarcity through using and recycling natural resources. Plants irrigated with fish wastewater like cantaloupe showed increased growth parameters and seed germination percentage [10]. Also, the use of algae in the form of algal bioconcentrate or extract would reduce the use of chemical expensive and rather hazardous fertilizers. Algal extracts/bioconcentrates in particular are beneficial in combating salinity adverse effects and improving seed germination and plant growth [11]. Moreover, many cyanobacteria are nitrogen fixers such as *Nostoc* spp. and *Anabaena* spp., where they take in the nitrogen from the atmosphere and then convert it into ammonia which is usable as nitrogen source, thereby, increasing the bioavailability of nitrogen, enhancing the harvest yield and quality especially in rice fields [12]. Furthermore, it is possible to increase the crop productivity through the combined use of two biofertilizers. For example, it was revealed that mycorrhizal activity could even be further enhanced by adding algal extract to mycorrhizal inoculums. This in turn significantly enhanced the growth of *Chamaedorea elegans* shrub [13]. This combined application was proved to be effective even in slightly salinized soils which would reduce the need for irrigation with freshwater for growing important crops such as broad beans [14] and black-eyed peas [15].

2 Mass Culture of Algae

Man-made ponds are to be built for growing microalgae to be used as fish feed and biofertilizers. This open system offers many advantages for growing algae as they are economical with a relatively high yield of algae and cheap operating costs. Ponds, usually lined with plastic or cement, are about 20–35 cm deep to ensure adequate exposure to sunlight. A more developed mass culturing system is the raceway pond. This system is made of a closed loop recirculation channel that is 0.3 m deep where circulation is provided by the paddle wheel. This system is usually built in concrete or compacted earth. Inorganic nutrients are added in the day time where the flow is allowed. Biomass is harvested behind the paddle wheel. The paddlewheel operates all the time to prevent sedimentation [16]. Algae can be harvested through the addition of ferric chloride and aluminium sulphate whose stock concentrations are 0.0600 mg/ml and 0.0565 mg/ml, respectively [17]. Those chemical flocculants neutralize the charges on the algal surface thereby causing them to flocculate and coagulate [17]. Another method for algal harvesting is filtration through gauze sheets of small pore sizes [10].

3 The Multiple Uses of Algae in the System

3.1 Algae as Fish Feed

Microalgae are autotrophic photosynthetic microorganisms that represent food source for many aquatic animals even at the larval stage [18]. Microalgae can form the start of a chain of aquaculture as they are an important food source for fish and crustaceans [19, 20]. Algae represent an alternative protein source for cultured fish, particularly in tropical and subtropical regions where algae production is high and their good protein, vitamins and essential fatty acid contents are documented [21].

They also act as stabilizers for water quality as they photosynthesize and increase oxygen concentration needed for respiration [18]. The appropriate size of algae for ingestion by aquatic animals varies, where the size range of 1–15 μm is most appropriate for filter feeders whereas size of 10–100 μm is more suitable for grazers [22–24]. There are several criteria that microalgae must meet to be used for fish nutrition, such as their rapid growth rates under a wide range of temperature and light intensity as well as their appropriate nutrient composition, most importantly proteins and fatty acids composition. The latter must be particularly high in certain fatty acids such as eicosapentaenoic acid, arachidonic acid and docosahexaenoic acids [25]. Other nutritional attributes such as minerals [26] and pigments [27] contribute to the nutritional differences of microalgae. The microalgal nutritional value can vary under different growth conditions [27]. Also the algal species used must lack the ability of toxin production [28]. In that regard, [27] reported that the marine eustigmatophytes *Nannochloropsis* sp. had the highest percentages of saturated fats (33% of total fatty acids), followed by diatoms (27%) and then chlorophytes (23%). It also has tannins [29]. Most importantly this alga contains several carotenoid pigments that have antioxidant effect [30].

Recently, [10] showed that this microalga was suitable as a supplementary diet to tilapia in Egypt where feeding on a diet supplemented with 5% dry biomass of *N. oculata* gave the best fish body weight. Previously, [31] showed that partial supplementation of fish meal with dried microalgae *Chlorella s*pp. and *Scenedesmus* spp. in Nile *tilapia* (*Oreochromis niloticus*) diets enhanced fish growth significantly. [32] found that fish fed diet containing 15% algae increased significantly the digestibility coefficient of dry matter (92.5%), crude protein (87.63%), ether extract (88.45%) and energy (81.41%). [33] fed the Nile tilapia with diets supplemented with various levels of green alga *Ulva rigida* and brown alga *Cystoseira barbata* meal. The highest values for weight gain were for fish fed the 5% *Cystoseira* diet and 5% *Ulva* diet. The results suggested that those algal meals could be used as diet supplements in tilapia diets. This specific fish is known for its low water quality, efficient feed conversion and good consumer acceptance.

3.2 Algae as Biofertilizers

According to [34], farmers have adopted the strategy of increasing crop yields by applying large amounts of chemical fertilizers and pesticides. However, the negative effects of heavy applications of those chemicals, in terms of production, environment and quality deterioration, are apparent [35]. Since the ultimate goal of sustainable agriculture is to develop farming systems that are productive, profitable and energy-conserving, the use of biofertilizers would seem to be the most plausible alternative to chemical fertilizers either partially or completely. This will result in the conservation of natural resources as well as increasing food safety and quality. Thereby the use of the algal bioconcentrate as a nutritive biofertilizer is proposed. Algae can be used as biofertilizers through using algal bioconcentrate or hydrophilic extract. Algal bioconcentrate can be prepared by collecting algal biomass, freezing it and thawing it leading to its rupture and release of its contents. The bioconcentrate can be homogenized and applied as either soil fertilizer or foliar spray. Alternatively, the algal biomass is to be homogenized in water, and the hydrophilic extract is taken either by filtration or centrifugation. [15, 36] reported that germination percentage of seeds of *Lactuca sativa* and their growth were significantly increased as a result of microalgal treatment of *Chlorella vulgaris*.

3.3 Algae as Soil Conditioners

Microalgae are all photosynthetic thereby adding to the carbon reservoir of soil where some cyanobacteria genera form soil crusts, e.g. *Scytonema*, *Nostoc* and *Microcoleus*, are reported to be major contributors in biocrusts which greatly increase the stability and fertility of the soil. For example, [37] reported that *Microcoleus vaginatus* acts as a photosynthetic ecosystem engineer of arid soils. The polysaccharide sheath of cyanobacteria, in particular, helps improve soil texture [38, 39]. Also, cyanobacteria with their polysaccharide sheath can ameliorate the effect of salinity in salt-affected soils [40]. According to [39], microalgal polysaccharides act as soil stabilizers and conditioners as they bind soil particles together, improving water retention and making facilitating soil compaction. The inoculation with polysaccharide-producing green alga *Chlamydomonas mexicana* has been performed in the soils of the southwest of USA and Mexico in the seventies [8]. This resulted in the increase in polysaccharide content by 129% of the uppermost layer only 2 mm which enhanced soil quality as well as crop productivity [39].

4 Application of Chain Aquaculture in Egypt: A Case Study on a Bench Scale

Quite recently, a research study was conducted [10] to evaluate the potential of establishing sustainable aquaculture chain for growing algae, fish and plants. Brackish underground water from Wadi El Natrun was used to establish an algal mass culture of the eustigmatophyte alga *Nannochloropsis oculata*. The highest biomass obtained was when the water was supplemented with growth medium $BG_{11}$and Na acetate. The biochemical analysis of cultured biomass of *Nannochloropsis oculata* in brackish water showed high phenolic contents including flavonoids which have antioxidant effect on harmful free radicals [41]. This specific alga is well-known for its nutritional fatty acid composition as it is rich in eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), palmitoleic acid, oleic acid, linoleic acid, linolenic acid and arachidonic acid [42].

This renders it a suitable natural fish feed for the cultivation of hatchery *tilapia* fish. The biomass of *Nannochloropsis oculata* showed high nitrogen content which is essential for the biosynthesis of proteins, nucleic acids and membranes [43]. Calcium content was also high which is essential for fish feed as it is important for fish bone development which is made of calcium phosphate. The moderate content of *N. oculata* biomass which was cultured on the brackish water provides good conditions for *tilapia* growth as high or low content of sodium causes problems in the fish body especially in blood pressure or electrical activity [44]. Supplementation of fish feed with *N. oculata* biomass (a mixture of 50 g dried pure powder of *N. oculata* with 1Kg of fish food) resulted in significant body gain and an increase in protein content. The study also showed that using fish wastewater in culturing three varieties of cantaloupe seeds caused a significant improvement in germination percentage and seedling growth parameters as compared to irrigation by freshwater. The study concluded that the establishment of chain aquaculture is feasible on the brackish underground water.

5 Applications of Algal Extract as Biofertilizer of Cowpea in Egypt: A Case Study

Abd El Sattar [45] studied the effect of treatment with different cyanobacterial extracts (aqueous and organic) of two strains (*Aphanizomenon flos-aquae* and *Phormidium* sp.) on germination of cowpea seeds grown under salinity-induced stress conditions. She found that aqueous extract was more stimulating to germination than organic extract in terms of germination percentage, enzymatic activity, nucleic acid, protein and total soluble sugars, whereas stress indicators such as proline content, lipid peroxidation and relative permeability of the root membranes were lower than the organic extract. Therefore, aqueous algal extracts alleviated the harmful effect of salinity stress on seed germination. This can be used on a vast scale as an inexpensive and eco-friendly farming policy to counteract the hazardous effect of salinity on plants especially during the critical period of seed germination where salinity can inhibit it either partially or completely. She also studied the effect of using cyanobacterial extracts and mycorrhiza biofertilizers on seedling growth under salt stress. Results showed that morphological growth parameters were significantly increased as a result of biofertilizer treatment especially when using the aqueous extract of the cyanobacterium *Aphanizomenon* sp. indicating the improved water uptake due to those treatments (Table 1). The results of chemical analyses showed increased content of photosynthetic pigments as well as photosynthetic activity (indicated by Hill reaction) as compared to control under salt stress (Table 2). This high rate of photosynthetic activity would result in an overall increase in growth-related metabolites such as carbohydrates, proteins and nucleic acids (Tables 3 and 4) with decreased proline content as a result of biofertilizer treatment thereby indicating the mitigation of stress conditions. The treatments also caused an increase in the root mineral ion content and hormonal content thereby increasing water absorption (Tables 5 and 6).

6 Conclusion

The establishment of sustainable agriculture faces many challenges including:

1. The limited agricultural land plots and fertilizer supply due to urbanization and eroding fertile soils which lead to decrease in food supply that meets the demand of the vast population.

Table 1 Effect of aqueous extract of *Aphanizomenon*, mycorrhiza, salinity and their combination on growth criteria of cowpea plant (90-day-old)

Treatments	Shoot length (cm)	Shoot fresh wt (g)	Shoot dry wt (g)	Root length (cm)	Root fresh wt (g)	Root dry wt (g)
Control	12.83	32.57	4.79	10.37	2.45	0.63
Aphanizomenon	14.6	44.31	7.24	13.43	2.59	0.86
Mycorrhiza	13.06	52.51	8.46	11.45	3.08	0.90
Aphanizomenon + mycorrhiza	17.10	36.39	5.81	11.26	2.25	0.55
Salinity (−0.2 MPa)	10.43	18.2	2.93	10.6	1.27	0.36
Salinity + *Aphanizomenon*	13.43	24.54	3.31	11.2	0.83	0.27
Salinity + mycorrhiza	14.15	58.07	9.17	13.56	3.03	0.78
Salinity + *Aphanizomenon* + mycorrhiza	14.46	30.99	4.10	14	1.85	0.42
L.S.D. at 5%	6.63	16.31	3.46	5.4	1.43	0.35
L.S.D. at 1%	7.66	21.45	4.36	6.4	2.25	0.48

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Table 2 Effect of aqueous extract of *Aphanizomenon*, mycorrhiza, salinity and their combinations on photosynthetic pigments content (mg g^{-1} d.m.) and Hill reaction (μ ferricyanide mg^{-1} chl. g^{-1} f.m.) of cowpea plant (90-day-old)

Treatments	Chl. *a.*	Chl. *b.*	Carotenoids	Total pigments	Hill reaction
Control	4.01	1.81	5.38	11.2	0.128
Aphanizomenon	4.30	2.06	6.42	12.78	0.231
Mycorrhiza	7.31	3.44	17.20	27.95	0.218
Aphanizomenon + mycorrhiza	5.77	2.53	9.49	17.79	0.197
Salinity (−0.2 MPa)	2.16	1.27	4.01	5.43	0.105
Salinity + *Aphanizomenon*	4.07	2.06	6.18	12.31	0.295
Salinity + mycorrhiza	6.44	3.13	14.33	23.90	0.774
Salinity + *Aphanizomenon* + mycorrhiza	2.48	1.31	4.05	5.80	0.118
L.S.D. at 5%	0.23	0.236	2.87		0.013
L.S.D. at 1%	0.23	0.236	3.1		0.022

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Table 3 Effect of aqueous extract of *Aphanizomenon*, mycorrhiza, salinity and their combination on carbohydrate content and on phenolics and flavonoids content (mg g^{-1} d.m.), of cowpea plant leaves (90-day-old)

Treatments	Total soluble sugars	Polysaccharides	Total carbohydrates
Control	5.12	48.05	53.17
Aphanizomenon	6.92	31.61	38.53
Mycorrhiza	10.21	21.52	31.73
Aphanizomenon + mycorrhiza	6.98	38.60	45.58
Salinity (−0.2 MPa)	8.66	38.46	47.12
Salinity + *Aphanizomenon*	11.63	28.02	39.65
Salinity + mycorrhiza	15.33	19.21	32.70
Salinity + *Aphanizomenon* + mycorrhiza	8.68	23.02	34.54
L.S.D. at 5%	0.211		0.350
L.S.D. at 1%	0.406		0.410

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2. The pollution where Egypt's ever-increasing population leads to a tremendous increase in pollution levels especially in the Nile River which also receives wastewater from domestic and industrial drainage thereby affecting water quality and increasing its toxicity. This high pollution level leads to tremendous decrease in the quantity and quality of freshwater fish as well as massive killing of fish stocks due to pollution/illegal fishing methods.
3. The limited water resources, where remote vast areas in the desert are suffering from shortage of water as Nile River does not reach them where nearly 95% of Egypt's area is desert land.

Table 4 Effect of aqueous extract of *Aphanizomenon*, mycorrhiza, salinity and their combination on total soluble proteins (mg g^{-1} d.m.), nucleic acids and proline content (mg g^{-1} f.m.), of cowpea plant leaves (90-day-old)

Treatments	Total soluble proteins	Proline	DNA	RNA
Control	10.38	0.146	5.12	19.16
Aphanizomenon	15.82	0.095	5.78	22.87
Mycorrhiza	25.61	0.124	5.75	21.63
Aphanizomenon + mycorrhiza	24.42	0.167	5.78	22.22
Salinity (−0.2 MPa)	24.67	0.243	4.83	15.95
Salinity + *Aphanizomenon*	29.10	0.156	5.76	19.99
Salinity + mycorrhiza	25.95	0.145	5.90	18.77
Salinity + *Aphanizomenon* + mycorrhiza	25.35	0.237	5.26	19.91
L.S.D. at 5%	0.032	0.164	0.073	0.032
L.S.D. at 1%	0.039	0.207	0.083	0.032

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Table 5 Effect of aqueous extract of *Aphanizomenon*, mycorrhiza, salinity and their combination on mineral ions content (mg g^{-1} d.m.) of cowpea root (90-day-old)

Treatments	K	Na	Ca	Mg	P	Mn
Control	5.30	12.40	5.85	10.10	1.13	0.120
Aphanizomenon	6.20	7.80	6.85	8.30	1.11	0.105
Mycorrhiza	5.60	9.45	5.35	10.40	1.43	0.120
Aphanizomenon + mycorrhiza	5.70	15.35	4.90	9.60	2.66	0.080
Salinity (−0.2 MPa)	6.10	10.25	5.85	10.10	1.42	0.115
Salinity + *Aphanizomenon*	9.84	11.25	7.65	6.40	1.90	0.078
Salinity + mycorrhiza	5.10	8.10	5.85	10.10	1.24	0.110
Salinity + *Aphanizomenon* + mycorrhiza	5.20	16.95	11.75	11.30	2.14	0.100

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Table 6 Effect of aqueous extract of *Aphanizomenon*, mycorrhiza, salinity and their combination on hormonal content (mg g^{-1} f.m.) of cowpea plant (90-day-old)

Treatments	IAA	GA_3	ABA	Kinetin
Control	3.48	5.70	1.30	1.23
Aphanizomenon	3.57	7.80	0.675	1.64
Mycorrhiza	8.44	6.75	0.705	1.64
Aphanizomenon + mycorrhiza	13.20	6.60	1.30	3.54
Salinity (−0.2 MPa)	2.85	4.35	3.81	0.399
Salinity + *Aphanizomenon*	9.88	14.10	0.87	1.19
Salinity + mycorrhiza	14.89	7.05	1.05	1.98
Salinity + *Aphanizomenon* + mycorrhiza	8.59	8.10	0.60	1.47

(Reproduced with kind permission of Dr. Amira Abd El Sattar) [45]

Therefore, there is a need for innovative policies to allow the development of sustainable agriculture. The integrated aquaculture/agriculture approach seems to overcome several obstacles and challenges in conventional agriculture. Applying a balanced, wise and sound agricultural policy that takes into account the importance of economizing water usage combined with achieving successful integration between fish culture and agriculture would allow sustainable development. Establishing fish culture, namely, tilapia, in the desert has proven successful in countries with similar desert topology and climate. The plentiful unpolluted geothermal underground water would provide a solution to the limited water resources and would be used for growing algae, fish and plants. Aquaculture nowadays is an important source of animal protein that could meet the world's increasing demand. Nile tilapia (*Oreochromis niloticus*) is a major fish species reared in aquaculture because it shows rapid growth rates, high tolerance to low water quality, efficient feed conversion and good consumer acceptance. The system described is eco-friendly and maximizes the efficiency of water use. The fish wastewater is to be used for irrigation of plants thereby acting as natural fertilizers as waste from fish is rich in P and N which are essential plant nutrients, thus replacing the harmful chemical fertilizers needed for plant growth. The algae play multiple beneficial and cost-effective roles in that system. They will not only serve as biofertilizer and fish feed but also would work as soil conditioner/enhancer.

7 Recommendations

The author highlights the following recommendations:

1. Screening different habitats in the Egyptian territories for the selection of different algal strains of high nutritional/biotechnological value as well as rapid growth rate under minimal growth requirements
2. The maximum usage of underground brackish water for various purposes such as growing algae, fish and plants and recycling of wastewater
3. The expansion in inland aquaculture and testing the different aquatic animals for growth and proliferation in hot desert areas
4. The wide application of integrated aquaculture/agriculture approach
5. The use of algae as biofertilizers solely or in combination with other microorganisms such as mycorrhiza
6. The use of algae for improving soil conditions

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Managerial and Nutritional Trends to Mitigate Heat Stress Risks in Poultry Farms

Mohamed E. Abd El-Hack, Mahmoud Alagawany, and Ahmed E. Noreldin

Abstract Over the past years, developing genotypes of poultry is mainly driven objecting the best productive performance at optimal environmental conditions. Since recent elevation in extreme heat wave events and increased sensitivity of the modern genotypes of poultry to heat burden became an essential concern, heat burden led to remarkable economic losses in the poultry industry, particularly in arid (hot and dry over the year) and tropical (hot and wet over the year) regions in the world. Heat stress has been reported to cause marked adverse effects on poultry reproductive and productive performances. Many investigations have studied the harmful influences of heat burden on productivity and welfare of birds. The deleterious effects of heat stress on various species of poultry range from depressed body weight, the rate of growth, feed consumption, feed conversion ratio, egg yield, and egg weight to the impaired quality of egg and meat. Moreover, the deleterious impacts of heat burden on welfare and reproduction of birds have recently attracted increasing public awareness and concern. The earlier intervention strategies involving the nutritional additions and environmental management haven't been consistent in poultry for mitigating heat stress. So, there is a scope for exploring innovative approaches, involving the application of molecular techniques in poultry breeding to enhance poultry productivity in a sustainable manner as well as a genetic marker-assisted selection of poultry breeds for elevated heat tolerance. Subsequently, keeping in view the current situation, it is important to well understand the different molecular and cellular mechanisms included in poultry production. These mechanisms are like immunological and physiological aspects of poultry birds exposed to heat stress.

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Contents

1 Introduction and Objectives

Heat stress is of great concern in all kinds of poultry production. Severe heat stress adversely affects feed consumption, growth, hatchability, mortality rate, and other important traits governing the success of the poultry industry [1]. High environmental temperature leads to a wide range of deleterious impacts on physiological and performance traits in poultry [2, 3]. The thermoneutral region for most poultry species ranges usually between 18 and 20°C [4]. When the ambient temperature exceeds beyond this range, adverse changes are noted in growth rate, productivity, quality of egg, feed utilization, meat quality, carcass traits, fertility, and hatchability as well as physiological responses [5].

Heat stress occurs when the amount of heat produced by the animal surpasses its capacity to dissipate the extra heat to its surrounding environment. This imbalance may be governed by many meteorological factors like thermal irradiation, sunlight, humidity, air temperature, and movement as well as animal characteristics [6]. Two main categories of heat stress, i.e., acute and chronic, can be distinguished. The acute type refers to a short and rapid rise in environmental temperature. The chronic type refers to a high environmental temperature for a long period (days to weeks), permitting acclimatization to the environment. The heat stress elicits several physiological consequences, which have been discussed in the past [7]. These responses can be illustrated as reduced feed intake, increased body temperature, depressed immune response, alteration of blood pH, and electrolyte balance; in addition, decreased energy bioavailability in the cell, negative alteration in nutrient digestibility, absorption and metabolism, and impairment in endocrine functions; and furthermore, negative alteration in reproductive functions, disturbance in the

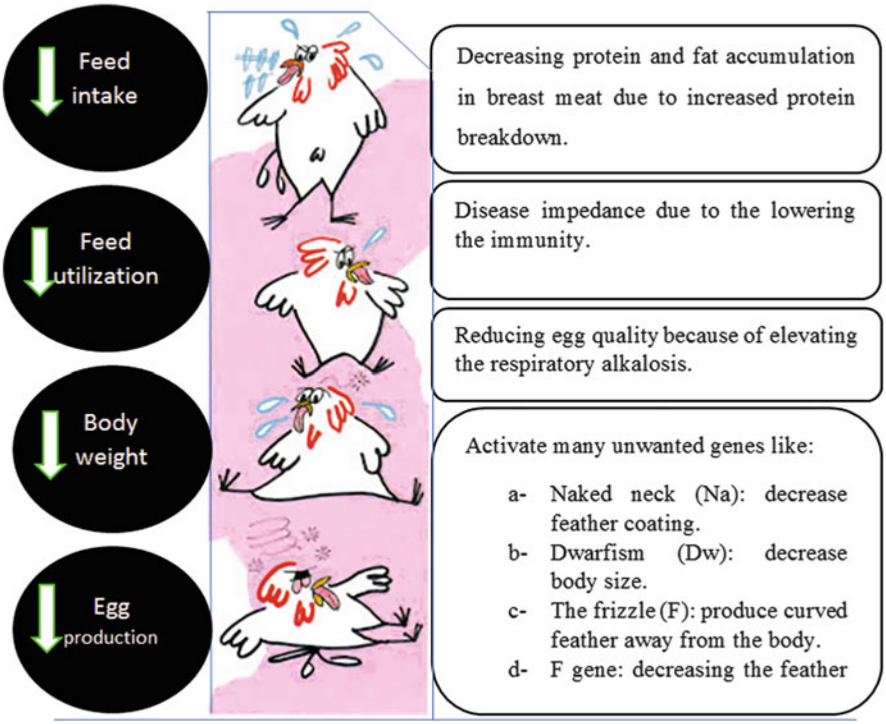

Fig. 1 Some of the deleterious impacts of heat stress

structure and function of the intestinal epithelium, alteration in gut microbiota, and increased the levels of circulatory corticosterone and cortisol [8]. This chapter highlights the harmful impacts of heat stress on poultry industry and how to cope with these bad effects in poultry farms.

2 Effects of Heat Stress

Several investigations have proved the harmful impacts of the environmental heat burden on poultry health and production (Fig. 1).

2.1 Live Body Weight and Weight Gain

The division of the direct and indirect effects of ambient temperature became impossible because the temperature of 26°C is recommended as thermally comfortable [9]. Onderic et al. [10] subjected growing Japanese quails to heat stress conditions (34°C for 8 h daily) and reported a significant decrease in body weight (9.1%) and body weight gain (11.0%) compared with birds reared at 22°C ambient temperature. Even with a narrow difference in temperature, growing quails reared under natural (32°C) and acclimatized conditions (26°C) decreased growth rate by 8.19% at 14–42 days of the study period [11].

2.2 Feed Utilization

The reduction of feed intake with an increase in the ambient temperature is well-documented for layers [12]. High ambient temperature causes economic losses through reducing feed intake, nutrient utilization, and feed efficiency of quails [13]. Birds reared under natural (32°C) and acclimatized conditions (26°C) resulted in 5.11% reduction in feed intake with a numerical decrease of 3.26% feed efficiency [11]. In the same context, feed intake and feed efficiency were decreased under heat stress conditions in broiler chickens [14].

2.3 Reproductive Performance

In males, heat stress causes testicular damage by rising the testicular lipid peroxidation due to increases in reactive oxygen species which adversely affect the semen volume, testes weight, sperm concentrations and motility, normal and live sperms, spermatids, spermatocyte, and spermatogonia [15].

In hens, heat stress causes oxidative injury to the small follicles, oviduct, and ovary, consequently significantly decreasing the ovary and oviduct weights, length of the oviduct, and the count of mature follicles [16].

Heat stress also may affect the sensitivity of gonads to metabolic hormones by changing the receptor numbers. Clark and Sarakoon [17] kept birds at high ambient temperature (38°C) and recorded a decrease in fertility percentage by 13% compared with control group reared under thermoneutral conditions (21°C). Miller and Sunde [18] showed that high ambient temperature adversely affects the production of estrogens, parathyroid, thyroid, gonadotropin, and calcitonin hormones. These physiological changes have been taken as an explanation for the changes in the components of egg, particularly the shell, shell membrane, albumen, and yolk, and consequently resulted in a reduction in egg fertility and hatchability. On the other hand, fertility and hatchability of eggs produced from large white female turkeys appeared to be unaffected when the females are reared at 12.8, 21.1, or 29.4°C ambient temperature [19].

2.4 Productive Performance

The high ambient temperature causes economic losses through reducing egg production [13]. On the same context, Sahin et al. [20] reported that egg production and egg weight of layers reared under heat stress conditions (34°) were decreased by 23.3% when compared with control group (22°C). Kilic and Simsek [21] stated that heat stress reduced egg production by 25% in layers reared under hot climate (25–29°C). Vercese et al. [22] noted that egg production in quails was not significantly affected by 33°C compared with 21°C, but was significantly lower by 6.6% at 36°C vs. 21°C. Egg production was also decreased by 36.2% with heat stress in laying hens [23]. The impaired productivity of poultry exposed to heat stress has been associated with a number of factors. These factors are like reduced appetite and feed intake as a mechanism to mitigate heat increment [24]. Moreover, impaired digestion and metabolism may be attributed to damage of intestinal morphology and lowered activity of digestive enzymes and thyroid hormones [25].

2.5 Egg Quality Criteria

Consumers prefer fresh eggs based on their characteristic features including yolk and albumen appearance and volume of air cell which can be confirmed by determining the yolk color, Haugh unit score, and malondialdehyde (MDA) level. In addition to the criteria above, producers are increasingly aiming to produce eggs with a normal eggshell thickness, eggshell breaking strength, and egg shape index, thereby facilitating the delivery of healthy eggs to consumers. Compared with the comfort temperature (21°C), cyclic heat stress of 27, 30, 33, and 36°C resulted in a reduction of egg weight of 5.1%, 5.9%, 6.9%, and 11.9%, respectively [22, 26].

In line, Sahin and Kucuk [13] mentioned that a high ambient temperature causes economic losses through reducing egg quality of quails. Panting is a normal action in birds exposed to heat stress, which lowers the levels of CO_2 and HCO_3 in the blood, thereby elevating the respiratory alkalosis by increasing the blood pH. The elevated respiratory alkalosis reduces the concentrations of calcium, which is the only form that can be used by eggshell gland to produce eggshell [27]. These alterations and reasons may explain why heat stress leads to poor quality of eggshell and a high number of cracked eggs.

2.6 Carcass Traits and Meat Quality

Heat stress can induce some negative changes in carcasses, breast and thigh meat, protein deposition, and the fat amount in breast meat as well as increase the abdominal fat [28]. Fat and protein deposition in the breast meat was decreased in poultry birds exposed to heat stress due to increased protein breakdown and decreased protein synthesis [29]. On the other hand, the carcass and organ yields (except decreased yields of heart and gizzard) of quails were not influenced by the environmental temperatures (26°C vs. 32°C), which may be due to a narrow difference in temperature [11]. The quality of meat could be reduced due to heat stress resulting from the generation of free radicals and reduction in antioxidant vitamins (C and E), which can cause lipid peroxidation of polyunsaturated fatty acids [10].

3 Heat Stress Mitigation Strategies in Poultry

Several strategies could be used to mitigate the harmful impacts of heat stress on poultry health and production (Fig. 2).

3.1 Genetic Strategies

In the long term, the single-trait election for yields has given rise to decreased heat bearing [30]. With elevating growth rates in poultry bodies, metabolic heat output has grown and the amplitude to bear increased temperatures has decreased [31, 32]. Commercial production of chickens based on intensive selection for increased production efficiency has resulted in crowded production environments, thereby increasing bird's exposure to heat stress [16]. In some cases, selection for production traits has increased the line's susceptibility to stressors [33, 34]. Under the heat stress circumstances, disease impedance of chicken is often dampened due to the lowering of immunity [35].

There are many genes that inspire heat bearing. Several genes, like the dominant gene for the naked neck (Na), affect the trait directly by decreasing feather coating [36], while the other genes, like the sex-linked recessive gene for dwarfism (dw), decrease body size and here with lower metabolic heat production. The frizzle (F) gene gives rise to the outline of feathers to bend away from the center of the body. Deeb et al. [37] observed that the F gene (as Ff) synergized the Na gene in decreasing the featherweight of broilers.

The slow-feathering (K) gene has been vastly used to "auto-sex" strain and breed-cross influences elevated heat loss through early growth, all of which can help the chicken to counter heat stress [38]. At the genetic level, the synthesis of most proteins is delayed, when chickens are attacked by thermal stress, but a collection of extremely protected proteins recognized as heat shock proteins (HSPs) is quickly synthesized. In a heat-stunned cell, the HSP may prevent destructed proteins from permanently influencing cell viability or may connect to heat-sensitive proteins and conserve them from destruction [39]. Polymorphism of heat shock protein genes based on SNP markers have been reported to be associated with heat tolerance of

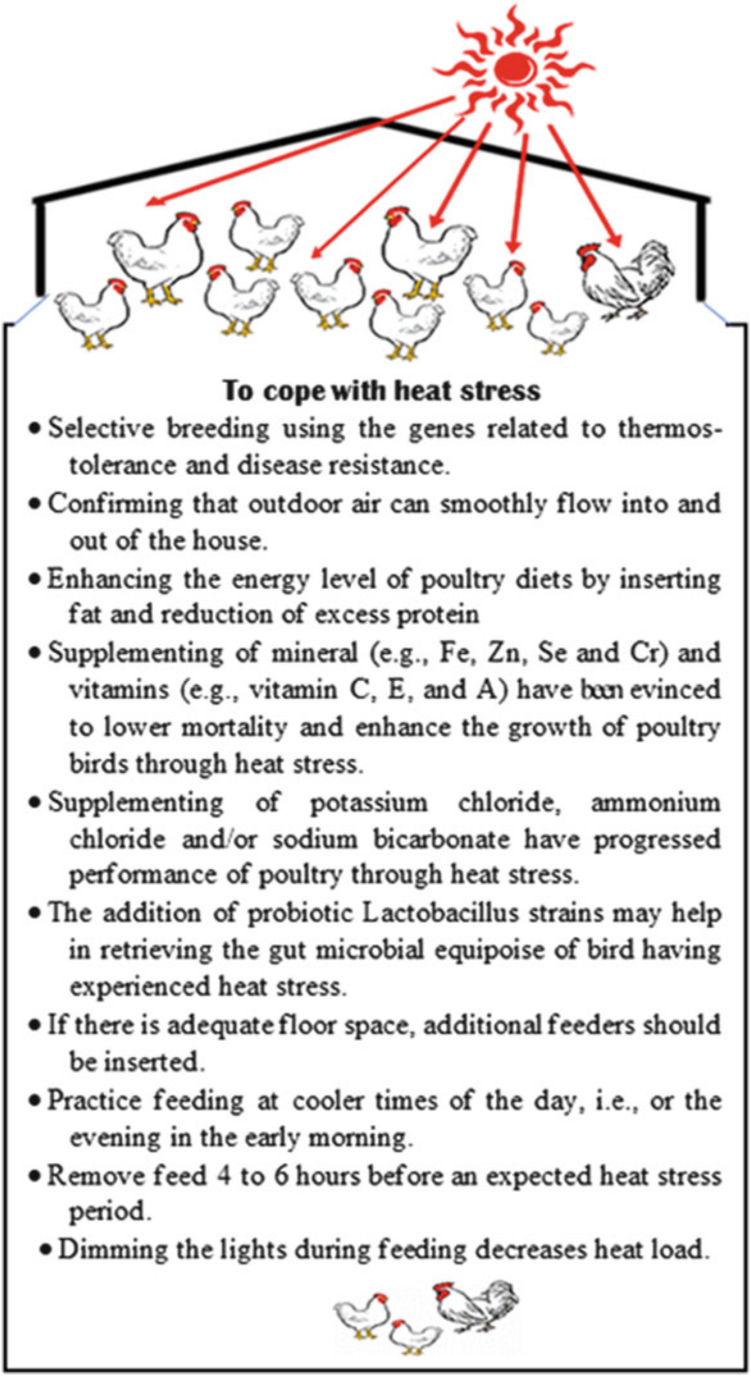

Fig. 2 Ways to ameliorate heat stress in poultry farms

poultry birds. Identification of SNP markers can aid in a marker-assisted selective breeding of poultry birds for heat resilience [40, 41].

For maintaining increasing trend of poultry production, improved thermos tolerance along with disease resistance is always desired. The previous studies have revealed that genetic variations form much of the basis for bird's response to heat stress; however, knowledge in this area is limited, and it needs further studies to explore its full potential [6, 42]. Genetic marker-assisted selective breeding using the genes related to thermos tolerance and disease resistance in poultry is the need of the hour for further enhancement in the poultry production.

3.2 Managerial Strategies

Confirming that outdoor air can smoothly flow into and out of the house is one of the solutions to diminishing heat stress in chickens' houses through warm weather. The simplest way for outdoor air is to influx through a house. The lesser airflow leads to a ferocious intensification of heat within the house. Consequently, this results in, decreasing inside to outside temperature differentials [43]. In humid and hot environments, open-style houses with enough air movement, proper shading, and water consumption are necessary. The provision of fresh air to a room should be great as possible due to the air motion that eases discarding of buildup carbon dioxide, ammonia, and moisture from the poultry houses [44]. A grass cover on the grounds embracing the poultry shed will minimize the reflexing of sunlight into the shed. Vegetation should be preserved trimmed to avert preventing air motion and to assist decrease rodent troubles. Shadow of trees should be determined where they do not limit air motion. Another factor that influences heat gain of a shed is the situation of the roof. A lustrous surface can reflect twice as much heliacal radiation as a dingy or rusty metal roof. Roofs should be preserved free of rustiness and dust. Roof reflectivity can be elevated by designing an aluminum roof or by painting and cleaning the surface with metallic zinc paint. The use of circulation fans is recommended for proper ventilation. The major objective of circulation fans in a naturally ventilated house is to generate air motion over the chickens to increase convective cooling. In general, it is preferable if circulation fans are placed toward the center of the house, where air motion tends to be most needed and directed to breathe with the long axis of a house. Circulation fans should at all events be set up in rows. To maximize air motion over the chickens, circulation fans should at all events be set up 1–1.5 m above the floor and obliqued downward at approximately a 5° angle [43].

In poultry, heat loss and the heat production are linked to heat stress. Both, body heat loss and body heat output, could be influenced by management. Adequate ventilation is vital for heat stress management in poultry birds. Heat loss by evaporative heat dispersal is connected to the proportional humidity of the surrounding ambiance [6]. Therefore, high humidity with high temperature is more injurious to broiler performance than low humidity with high temperature. The evaporative heat loss reduces with raising humidity and increases along with temperature [45]. Early heat conditioning (EHC) appears to be one of the hopeful styles in promoting heat resistance of broiler chickens. Early heat accommodation attributes to the practice of offering broiler chicks high temperature (36°C) for 24 h at 3–5 days of age [45]. Where possible, and in particular in older broiler houses with less efficient ventilation, it is right practice to decrease stocking consistencies in the summer [46].

3.3 Nutritional Strategies

Feed conversion in broilers undergoes to considerable variations due to ambient temperature and migrant changes. All studies point that elevated temperature decreases the competence of used feed energy for productive objectives. However, only part of the decreased rendering of broilers is because of minimized feed intake, and the remnant is on account of elevated temperature per se [47]. It is mentioned that the decrease in broiler growth because of diminished feed intake ranges from 63 to 67% [47, 48]. In hot regions, it is the widespread practice now in formulating broiler rations to enhance the energy level of these diets by inserting fat. This method not only elevates the energy intake but also decreases the specified dynamic influence of the diet, which assists chickens to overcome heat stress [47]. Nutritional manipulations, such as the addition of fat [49] and reduction of excess protein [50], are recommended to decrease the unwanted influences of heat stress. The insertion of fat to the diet also seems to elevate the energy value of other feed ingredients [51] and has been observed to lower the average of food passage in the GI tract and to elevate nutrient employment [52]. Through hot seasons, decreased protein diets supplemented with diminishing amino acids conduct better outcomes than the elevated protein diets. The insertion of essential amino acids to a diet with a lopsided amino acid profile or poor-type protein assists showing by lowering heat boost and the hurtful influences of elevated temperature. Therefore, the poultry industry has gone after the practice of regulating the dietary grads of amino acids and protein to confirm enough intake of these necessary nutrients [47]. Dietary electrolytes are one of the responses to amino acid supplements which diverge with various dietary factors at elevated temperature [53].

Heat stress decreases the liver and serum concentrations of vitamins (e.g., vitamins C, E, and A) and minerals (e.g., Fe, Zn, Se, and Cr) and increases the mineral excretion from the body. Moreover, mobilization of vitamins and minerals from tissues and their excretion are increased under heat stress rising marginal vitamin and mineral deficiency [20]. Mineral and vitamin supplementations have been evinced to lower mortality and enhance the growth of poultry birds through heat stress. The dietary electrolyte equilibrium is more serious at elevated temperature than at normal temperature. Conservation of both blood pH and carbon dioxide is pivotal to heat-stressed birds, and the insertion of potassium chloride and ammonium chloride to drinking water is coveted to keep this balance. The occurrence of alkalosis in heat-stressed chickens had been recognized for a long time, and the supplement of potassium chloride, ammonium chloride, and/or sodium bicarbonate has progressed performance of poultry by enhancing feed and water intake [54]. The addition of $NaHCO_3$ relieves the bicarbonate (HCO_3^-) scarcity that resulted from a developing respiratory alkalosis caused by panting [55]. The supplementation of extra electrolytes, vitamins, and antioxidants to the drinking water is also advantageous through heat stress. Because heat stress always minimizes appetite and thus lowers nutrient intake, the use of an electrolyte and vitamin pack in the drinking water for 3–5 days during a heat wave has been observed to be profitable in most cases. Vitamin C (ascorbic acid) addition might be the most beneficial among vitamins, and use of vitamin C in the drinking water or in the feed has become a prevalent practice in hot regions. Several nutritionists recommend the addition of 1 g ascorbic acid/l drinking water during heat seasons [47]. The ferocious effect of heat stress on egg production can also be relieved by dietary addition of vitamin A (8,000 IU/kg diet) [56]. Vitamin E addition is salutary to the egg production of hens at elevated temperatures and is linked with an excess in yolk and albumen solids and feed intake [57]. Heat stress could stimulate the undesirable mutations in domestic bacterial microbiota [45]. The addition of probiotic Lactobacillus strains may help in retrieving the gut microbial equipoise of bird having experienced heat stress [58].

Apart from the nutrient supplementation, feeding practices [59] suggested below are mentioned to upgrade the performance of chickens under heat stress. The perfect physical quality of feed (pellets, crumb, or mash) is mentioned to enhance appetite. If there is adequate floor space, additional feeders should be inserted. Feed should not be stocked for longer than 2 months, especially in summer, to lower the potential of mycotoxin foundress. Practice feeding at cooler times of the day, i.e., in the evening or early morning. Feeding birds at cool times enables birds to pretend for what they have not eaten through the day. Laying hens increase their calcium intake through the evening as eggshells are normally formed through this time. Remove feed 4–6 h before an expected heat stress period. Birds should not be disturbed or fed through the hottest part of the day. Dimming of lights during feeding or using low light ferocity through periodical feeding lowers activity that decreases heat load.

4 Conclusions

With increasing the global temperature and lowering heat tolerance of the modern genotypes of poultry, heat stress has emerged as a major concern causing many economic losses to poultry production. Heat stress causes harmful influences on growth performance, carcass traits, meat quality, egg production, egg quality, and reproduction. To date, many published studies in heat stress in poultry focused mainly on exploring the strategies to interfere with the conditions which cause heat burden. These conditions include nutritional supplementation and environmental management, while the effectiveness of these conditions varies due to breed, sex, age, geographical location, and management.

5 Recommendations

Several points should be considered to mitigate heat stress in poultry farms like ensuring that outdoor air can smoothly flow into and out of the poultry house; moreover, practicing feeding at cooler times of the day, removing feed 4–6 h before an expected heat stress period, and dimming lights during feeding; and furthermore, using good ventilation design, improving the energy level in poultry diets and enriching the diets, and drinking water with minerals, vitamins, antioxidants, and probiotics.

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Nutritional Strategies to Produce Organic and Healthy Poultry Products

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Abstract Agricultural poultry products including eggs and meat are important sources of crude protein, lipids, minerals, and micronutrients that play a critical role in basic nutrition. Traditionally, meat and eggs are associated with negative factors in human health, mainly due to their content of triglyceride and cholesterol. It is well known that the response of serum cholesterol levels in human to dietary cholesterol consumption depends on many factors like hormonal factors, genetic makeup, ethnicity, and the nutritional condition of the consumer. Recently, there has been increasing demands for organic food, which are expected to continue to increase in the near future, due to their ability to reduce the risks of many diseases and enhance the physical and mental well-being of the consumer, besides satisfying hunger and supplying substantial nutrients. Organic foods of animal origin are produced by feeding the animal on a specific diet or by using some techniques, like induced genetic mutation, genetic engineering, cross-breeding, etc. with an aim to guarantee the presence of nutrients, which may be useful to human health. The organic foods of poultry origin may only include organic eggs and organic chickens. To produce organic/designer food, it is essential to study the available and sustainable nutritional strategies and evaluate knowledge-based alternatives of growth-enhancers as well as develop more efficient models and protocols for quantification of the bioavailability and bio-accessibility of bioactive compounds for health studies in animal and human. Organic eggs, viz., specialty, vegetarian, immune-powered, and functional and designer eggs, do have increased content of vitamins, minerals, and essential pigments like carotenoids, lowered cholesterol and fat, balanced ratio of omega-6 to omega-3 fatty acids, antibacterial active principles, and an

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additional boost of antibodies. On the other hand, organic meat contained a higher concentration of tocopherol and conjugated linoleic acid, omega-3 fatty acids, protein, and amino acids; all these factors contribute to the maintenance and the improvement of consumer health. This chapter offers a simple overview of the significance and health benefits of organic poultry products, and it explores the possibilities of the production and development of organic food by technological strategies.

Keywords Agriculture, Cholesterol, Eggs, Health, Meat, Omega-3 PUFAs, Organic products, Poultry

Contents

1 Introduction and Objectives

The production of organic poultry has increased in several countries, but it is still relatively small. This positive trend is as a result of increased preferences of consumers for organic poultry products (meat and eggs) that are perceived to be secure under the production system. These products reduce the use of drugs, antibiotics, synthetic fertilizers, genetically modified crops, pesticides, and hormones which lead to many adverse effects on consumer health. The guidelines for this system were expanded in an attempt to study and use an alternative to traditional production [1].

In recent decades, foods are intended to satisfy hunger and supply necessary nutrients for consumers, as well as to reduce or prevent nutritional diseases and enhance the mental and physical well-being of humans [2]. Since human nutrition in most of the developed countries depends on excessive consumption of cholesterol, protein, n-6 polyunsaturated fatty acids (PUFAs), saturated fatty acids (SFA), sodium, or calories, consumption is deficient in n-3 PUFA, antioxidants, and fiber. The imbalances in these nutrients are partly responsible for the high incidence of obesity and cardiovascular diseases (CVD) as reported by Mokdad et al. [3]. Generally, the use of lower-fat diets is accepted to prevent CVD. This is based on consumption of total fat of 25–35% of total calories, SFA less than 7–10%, and trans-fatty acids no more than 1%, unsaturated fats, mainly n-3 PUFA. The monounsaturated fats (MUFA) should represent the rest of the calories from cholesterol and fat, for a total of less than 300 mg/day [4].

By feeding poultry to obtain nutritionally modified poultry products or by using some recent techniques such as genetic engineering, cross-breeding, induced genetic mutation, etc., the organic poultry products are produced to increase or decrease the presence of some nutrients or to alter them. Organic poultry products can be created with sufficient concentrations of essential nutrients which are considered very beneficial for consumer health. A large number of nutrients such as amino acids, some vitamins (C and E), L-carnitine, beta-carotene, and other phytochemicals have been identified to be very efficient in reducing the incidence of diseases [5–9]. It is interesting that the antioxidants included in the organic products help in lowering the oxidative stress and heart and joint diseases as well as cancers and even inflammatory arthritis occurrences [10, 11]. By increasing the number of natural antioxidants in poultry products, it can help to keep the consumers healthy for a long time and increase their lifespan. The quantity of some nutrients can be increased in the diets to make them more efficient. In addition, it is possible to decrease some nutrients from the diets such as proteins and carbohydrates that are consumed a lot or make them indigestible without influencing the organoleptic property of diet [12–14]. Therefore, the poultry industry is one of the most important bases for provisioning the human in the world with high-level protein-rich products. Dramatically, poultry production in a large scale has improved the efficiency of poultry production and provides the consumers with high-quality foods (poultry products) at low prices [12, 15, 16]. This chapter offers a simple overview of the production and health benefits of organic and functional poultry products, and it explores the possibilities of the development of organic food by technological strategies.

2 Poultry Diets and the Organic Standards

The poultry nutrient requirements are very different from those of ruminants. Poultry is particularly sensitive to nutrient quality due to their rapid growth, so the use of feeds rich in fiber like hay or pasture is relatively little in their feeding [17]. Poultry has very specific requirements for indispensable amino acids, particularly lysine and methionine (first and second limiting amino acids). Under conventional systems, poultry diets are supplemented with synthetic crystalline amino acids. In an organic system, these additions are not permitted, so alternative feeds have to be found such as organic soya. It is always difficult and expensive, and these sources are main contributors to the high feed costs [18].

All organic poultry should be fed on 100% organic feeds, but because of the limitations in sourcing organic feeds, a proportion of nonorganic feed ingredients can be used in poultry diets (Fig. 1). Living conditions required by organic regulations include outdoor access, exercise areas, shade, shelter, fresh air, fresh drinking water, and direct sunlight. Practically, most poultry feedstuffs are purchased from feed mills, and the reality is that farmers will purchase the cheapest diets that comply with the standards [19, 20]. Producing as much feed ingredients from the farms as possible is one of the guidelines of organic strategies. The famous cereals grown on farms are triticale, wheat, and oats, and these cereals are often cultivated in combination with protein crops like peas. Oat crop is beneficial to broiler and layer

Fig. 1 Living conditions required by organic regulations include outdoor access, shade, exercise areas, shelter, fresh air, fresh drinking water, and direct sunlight

chickens because it contains high oil and protein contents, as well as relatively high contents of the essential amino acids [21].

There are few requirements to produce organic and healthy poultry:

- Must be reared organically on certified organic land.
- Must be fed certified organic diets.
- No drugs or antibiotics.
- Growth hormones are allowed in some cases.
- Must have outdoor access.

3 Feeding of Poultry for Organic and Healthy Products

Organic poultry must be fed diets sufficient to meet nutrient requirements, including energy sources, fatty acids, proteins, amino acids, minerals, vitamins, and fiber. Agricultural feedstuffs must be certified organic [19, 20]. The oyster shell may be used in laying hen diets as a calcium source to strengthen shells. All supplements and feed additives must be listed with the formulation, manufacturer, and full brand name in the producer's Organic System Plan.

Synthetic methionine is an indispensable amino acid that may be selected in certified organic supplements in limited amounts that are specified by the regulations [5, 6, 22]. FDA prohibits the use of hormone as a feed stimulant and growth promoter in poultry industry, so producers of organic poultry must not use them to enhance growth [23]. In addition, producers of organic poultry must avoid ingredients or additives such as nonorganic chick starter, which include antibiotics. On the other hand, arsenic is used in some nonorganic diets as a feed supplement and for protozoan parasite control. Thus, arsenic compounds should not be used in organic diets; use of arsenic is forbidden for production of organic crops, so it must not be used or applied to organic land through poultry manure [24]. Producers of organic poultry products must not use feed additives or supplements at levels above what is required for health maintenance and adequate nutrition [25].

Some nutritional strategies can improve the poultry ability to create high-quality products. The diet of poultry can affect chemical structure and composition as well as the nutritional value of eggs and meat products. For example, if birds are fed on rations that are deficient in some nutrients such as vitamins, minerals, amino acids, or any other nutrient, the eggs and meat produced by those birds will also contain a subnormal concentration of these components [12–14]. Therefore, improved poultry health via nutrition would reduce the need for administration of therapeutic drugs, which may decrease the chances of drug residues in poultry products. Furthermore, providing poultry with well-balanced diets would enhance the productivity, carcass quantity and quality, as well as food safety assurance system [26, 27]. The production of organic poultry products needs the careful determination of poultry nutritional requirements; therefore the chemical composition and nutritional value of feed ingredients must be adequate to meet the maintenance and production requirements, to protect health and welfare of the birds, and to ensure the good quality of meat and eggs as well. Nutritionists, food technologists, and researchers introduced low-fat products, due to their effects in some of the deadly diseases like CVD, cancer, and stroke [28].

Increasingly, consumers are aware of organic and functional poultry products that can have positive impacts on health status and disease prevention [29]. Rabbit and bird meat well fit the modern consumer demand for low-fat meat with low sodium and cholesterol levels and high concentration of unsaturated fatty acids [30, 31]. Rabbit and bird meat may also be considered as functional food products, providing beneficial components with positive impacts on consumer health such as vitamins, antioxidants, conjugated linoleic acid (CLA), and a balanced n-6/n-3 PUFA as well [32, 33]. The diet modification has been proposed to alter the profile of fatty acids by increasing the n-3 PUFA level. Use of some natural feed additives or their extracts such as algae, hemp, linseed, or rapeseed oils is a good source of n-3 fatty acid to enrich meat [34].

Normally, eggs are not rich in n-3 PUFA, so dietary modifications of n-3 PUFA in poultry rations determine enriched n-3 PUFA eggs [35]. By modifying layer diets, it would be achievable to increase vitamin E, selenium, and lutein levels. The easiest method is to create enriched eggs in LA, a precursor of docosahexaenoic acid that is considered to have a defensive impact on heart diseases [36]. For these reasons, the birds' ration should be rich in linseed oil; as a result, the yolk of the egg would be enriched with docosahexaenoic acid and alpha-linolenic acid [37]. Use of vitamin E in the layer diets at a level of 200 mg/kg has been reported to be a good antioxidant [38]. Mixing chia seeds as a rich source of ALA with flaxseed in laying hen diets successfully increased the level of ALA in egg yolk without undesirable effect on sensorial traits of eggs [39]. Fredriksson et al. [40] stated that increased ALA levels in layer diets indicated a higher level of DHA in egg yolk, demonstrating desaturation and elongation of ALA toward DHA. Supplementing 10–20% flaxseed in diets of laying hens can produce eggs with a high level of n-3 PUFA, like EPA, DHA, and α-LNA [41–43]. The α-LNA in flaxseed can be converted into DHA and EPA via the liver, the synthesized fatty acids are subsequently deposited in the yolk [44]. Tables 1 and 2 illustrate the proximate composition and chemical analysis of flax based on common measures.

Table 1 Proximate composition of flax based on common measures[a]

Nutrient	Whole flaxseed (11 g)	Ground flaxseed (8 g)	Flax oil (14 g)
Calories	50	36	124
Protein (g)	2.2	1.6	0
Fat (g)	4.5	3.3	14.0
Omega-3 PUFA (mg)	2,600	1900	8,000
Omega-6 PUFA (mg)	700	500	2,200
Fiber (g)	3	2.2	0
Calcium (mg)	26	18.9	0
Phosphorus (mg)	68.4	49.8	0
Magnesium (mg)	47.4	34.5	0
Folic acid (mcg)	12.3	9.0	0
Potassium (mg)	91.4	66.5	0

[a]According to the Canadian Grain Commission. The fat content was determined using the American Oil Chemists' Society (AOCS) Official Method Am 2-93. The moisture content was 7.7%

Table 2 Proximate analysis of flaxseed according to Martinchik et al. [45]

Nutrient	Flaxseed, %
Protein	20–30
Fiber	28
Biological value	77.4
Digestibility	89.6
Oil	35.45
Saturated fatty acids	10
Monounsaturated fatty acids	20
Alpha-linolenic fatty acids	>70
Vitamin E	9.2 mg/100 g of seeds
Lignans	Up to 0.7–1.5% of dry weight of seed

The quality of rabbit meat is quite constant. Indeed, in comparison with other species, no definite changes of meat traits are observed [46]. In similar to poultry, the impact of feeding on meat quality of rabbit is widely and well investigated. Hitherto, research is involved in using nutritional strategies to enhance the rabbit meat quality as healthy products by increasing their contents of antioxidants, vitamins, and n-3 PUFA without the use of antibiotics [47–49]. Extracts of plants with antioxidant properties possess different impacts on health, performance, and meat quality of rabbits [33]. Including essential oil of oregano plant in diets of rabbit improved shelf life of carcass parts during storage period [50].

4 Organic and Healthy Poultry Products

A poultry product is any material derived from the body of poultry such as meat, egg, feather, etc. [51]. A direct intervention to produce an organic food depends on poultry diet modifications via nutrient supplementation, where this is an attractive way to enhance the levels of health-promoting constituents of poultry products [52]. Such interventions as the basic approach will improve the bioavailability of nutrients in food products for human beings and significantly enhance the public knowledge about foods from animal origin [53]. Thus, application of these products is significant in poultry feeding and animal farming to improve the health and safety of poultry.

Organic foods including egg and meat can better be defined as “any modified food or food ingredient that may provide a health benefit beyond the traditional nutrients it contains” or “food that provides health benefits beyond basic nutrition” [54, 55]. There are many names of organic food products like healthy foods, functional foods, designer foods, nutraceutical food, pharma foods, etc. which play an important role in treating and preventing several diseases and considered as useful to consumers health [56, 57]. Organic food is a natural product having an additional nutrient or lacking some components from the chemical composition or food with the modified availability of a nutrient(s) or combination of these mentioned possibilities (Fig. 2).

4.1 Organic and Healthy Eggs

The brown and white eggs are considered valuable sources of foods. The concept of organic eggs has been introduced to improve the consumption of egg in the market. Along with chicken eggs, quail eggs, duck eggs, goose eggs, and turkey eggs are also available in the market for consumers. The organic egg contents are modified from the normal eggs. The normal egg provides 70 kcal in the form of fat, carbohydrates, proteins, cholesterol, fatty acids, and antihypertensive peptides (ovokinin and ovokinin 2–7) along with 12 important minerals and vitamins [58]. Surai et al. [59] and Surai and Sparks [60] pointed out that egg is a cheap source of high-quality protein

Fig. 2 Organic poultry products (egg and meat)

along with the balanced ratio of essential and nonessential amino acids as well as minerals and vitamins excluding ascorbic acid. On the other side, because of the high content of cholesterol (195–250 mg/egg), the per capita consumption of eggs is low. A decrease in egg consumption affects poultry industry; thus several attempts are being made to redesign and improve the biological and nutritional values of the egg [60]. With the advancement of the technology, the eggs may be available in the shops under several attractive names, which could be misguiding the consumers. Thus, appropriate guidelines should be developed for the naming of such eggs, and various advantages and disadvantages of consumption of such eggs should be said to consumers to avoid misconceptions. Several of these eggs are created and marketed in different countries including Egypt. Adjusting nutrient intake generates today's so-called organic or healthy food (Fig. 3), which has been applied to one or more of the following purposes.

4.1.1 Increased Minerals and Vitamins in Eggs

In laying hens, through dietary supplementation, it is possible to increase the concentrations of chromium (Cr), iodine (I), and selenium (Se) in eggs without moderating much the level of calcium (Ca) and phosphorus (P). The maximum part of mineral resides in an egg shell with large amounts of Ca and P. Supplemental chromium to layer diets at levels of less than 1 mg/kg has been shown to lower cholesterol in

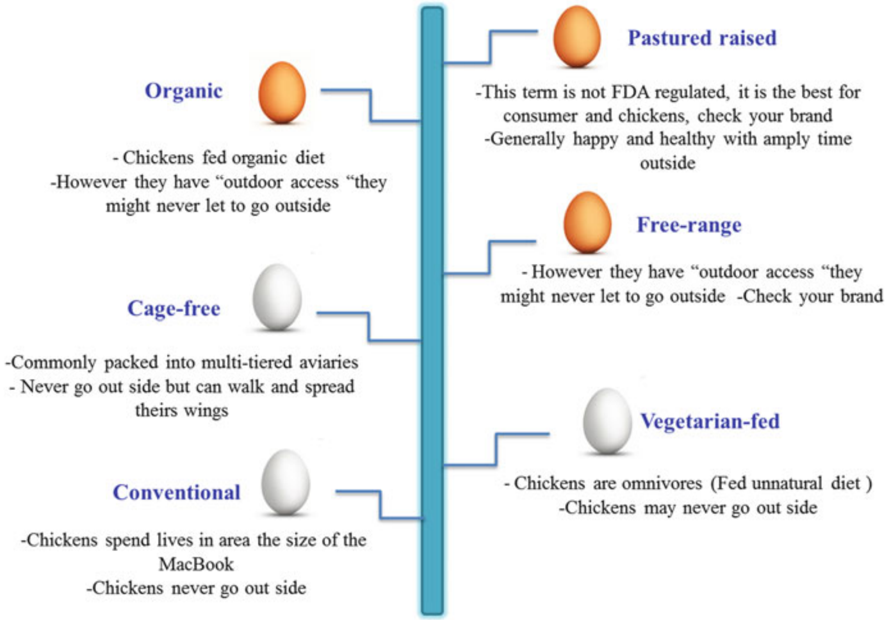

Fig. 3 A guide to pastured chickens vs. cage-free vs. free-range

egg and improve the egg quality [61, 62]. Functional egg contains 26 times higher vitamin E, 16 times more vitamin A, seven times higher Se, and six times more DHA content than a normal egg [62, 63]. They have a boost of antioxidants like Se, zinc (Zn), vitamin E, lutein, folate, flavonoids, pigments including carotenoids, phosvitin, lecithin, etc. to support and improve the immune response of the body. On the other hand, the organic egg contains increased contents of vitamins such as A, E, and ß-carotene [64, 65] that have been proposed, which would have a strong beneficial impact on some types of cancers. These (A, E, and ß-carotene) nutrients play an important role as antioxidants in protecting the body from free radicals.

4.1.2 Improving Fatty Acid Profile and Antioxidant Status

Healthy eggs contain a high proportion of unsaturated fatty acids to saturated fatty acids [66]. Interestingly, canola oil as an organic feed is used to change the ratio between saturated and unsaturated fatty acids. Healthy egg offers a balanced ratio of PUFA:SAFA (1:1) or omega-6 to omega-3 PUFA (1:1). Omega-3 PUFAs are essential compounds which improve the development of the brain and immune functions, cause a reduction in blood pressure, and lower platelet aggregation and atherosclerosis incidence. It is protective against some kinds of cancer and CVD [67, 68]. Different types of fatty acids and omega-3 present in yolk can be increased by using some feeds in layer diets like fish oil and meal, linseed, algae, and groundnut and safflower oils. Omega-6 PUFA includes essential fatty acids such as LA and arachidonic acid (AA); whereas linolenic acid (LNA), docosapentaenoic acid (DPA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) are examples of omega-3 PUFA. An organic egg is a potential vehicle to provide omega-3 PUFA which is important for normal function of the body, and its use decreases the risk of heart attack to the consumers [69, 70]. The level of DHA in blood increased by consuming functional eggs and could result in beneficial effects on several measurements related to health like an immune response, inflammation, and cardiovascular function [71]. The n-6 PUFA and n-3 PUFA in yolk egg were significantly decreased and increased with the birds fed different doses of dietary n-3 PUFA, in comparison with control, respectively [72, 73]. LNA and LA are the keys of n-3 PUFA and n-6 PUFA, respectively. The LNA is metabolized to DHA, EPA, and DPA, while LA is metabolized to AA in the body [74, 75]. Supplementation of n-3 PUFAs to maternal diets increased the level of n-3 PUFAs to total fatty acids in the egg yolk and tissues (brain, liver, and heart) of the hatched chicks [76, 77].

Among the different feed ingredients, flaxseed is a unique crop and is a rich source of α-LNA (50% of total lipid), oil (>38%), and crude protein (>22%) for poultry [78]. Yalcyn and Ünal [79] reported that hens fed rations supplemented with natural feed ingredients such as linseed meal and fish oil recorded the highest value of DHA, LNA, DPA, and EPA in yolk when compared to control. In Huoyan geese, dietary supplementation of flaxseed at the level of 15% resulted in improved levels of n-3 PUFA in egg yolks and enhanced the antioxidant parameters (GSH-Px, SOD, and catalase) of neonatal offspring in a dose-dependent manner. The malondialdehyde (MDA) level in the gosling liver decreased when flaxseed levels increased in the diet [80]. Other studies also stated that n-3 PUFA improved the hepatic activities of antioxidant enzymes such as catalase, GSH-Px, and SOD [81, 82]. On the same line, Bautista-Ortega et al. [83] reported that flaxseed supplementation improved the activity of catalase in the heart of hatched goslings to the layer diets. While, they failed to achieve any effect on activities of antioxidant enzymes like GSH-Px, catalase, SOD, and glutathione reductase in the brain, liver, and lung of goslings from high n-3 PUFA eggs. These results indicated better antioxidant parameters for the liver and other organs, which may lead to better protection from oxidative stress and free radicals. Additionally, the indicators of lipid peroxidation like a lower content of MDA in the organs reflected this result [50].

4.1.3 Hypocholesterolemic Effect

Cholesterol is mainly saturated fat. Dietary manipulations and use of drugs help in reducing the content of cholesterol in an egg. Some drugs have been successfully used in reducing cholesterol content in the egg by 50% in the functional eggs [84, 85]. Use of PUFA in poultry rations helps in lowering the contents of cholesterol and total lipids. Numerous studies were conducted to minimize the deleterious impacts of cholesterol and triglyceride in poultry products. The cholesterol contents in blood and yolk were lowered by 13.67% and 19.13%, respectively, with birds fed rations enriched with alfalfa meal in comparison with the basal diet [86]. The beneficial impact of alfalfa meal as hypocholesterolemic may be partially attributed to suppression of lipogenesis in the liver. Additionally, level of cholesterol in egg yolk was lowered with feeding low-fiber alfalfa meal; the hypocholesterolemic role of alfalfa meal may be due to the presence of saponins in their contents [87]. In line, Chen et al. [88] pointed out that dietary supplementation of flaxseed lowered levels of total cholesterol in the yolk. Contrarily, Botosoglou et al. [89] and Petrović et al. [90] stated that the use of 5% and 10% flaxseed or its oil in the diet of laying hens did not affect the cholesterol levels in the egg yolk. Also, Hayat et al. [42] and Petrović et al. [90] confirmed that the cholesterol content in egg yolk was not influenced by different sources of lipid but was influenced by the hen's age. However, the effect of reducing cholesterol may be different in different avian species, and its mechanism needs to be clarified.

4.1.4 Improving Yolk Color and Its Pigments

Using the natural feed ingredients such as corn, corn gluten meal, alfalfa meal, corn distillers dried grains with solubles (DDGS), etc. in laying hen diets lead to improving the egg yolk pigments [86, 91] since the yolk color is a reflection of its content of the pigments. Carotenoid pigments are hydroxy compounds named xanthophylls (most effective – zeaxanthin and lutein). Also, these pigments are mostly found in the yolk, and they are essential in increasing antioxidant efficacy against peroxidation of lipid [92] and reducing or preventing risks of cataract [93]. Moreover, plants rich in pigments such as carotenoids may improve the oxidative stability which is good for the health of animal and human. Also, modifying the color of egg yolk, β-carotene as a natural antioxidant plays a critical function in ensuring a stronger immune system and improving the health care [94]. These pigments are mostly high in some ingredients and meals like yellow corn and corn derivatives (gluten meal and DDGS), alfalfa meal, soybean meal, marigold-petal meal, and dried algae meal [86, 91]. Fortunately, these pigments are efficiently transmitted to the yolk when using these ingredients in laying hen diets [86, 95]. In comparison with the control diet, the score of egg yolk color was increased when hens were fed 6%, 9%, and 12% DDGS diets at 29, 33, 37, and 41 weeks old [96]. In line, Shalash et al. [97] and Deniz et al. [98] observed that increasing DDGS levels to 15% or 20% in hen rations increased the score of egg yolk color. The content of β-carotene in egg yolk was increased by 97.45% with birds fed alfalfa meal diets in comparison with control diet [86]. Akdemir et al. [99] confirmed that the content of yolk carotenoids was improved with birds' diets supplemented with carotenoid-rich plants. Contrarily, Lumpkins et al. [100] reported no effect of DDGS on the score of yolk color when 15% DDGS was supplemented to the diets of laying hens.

4.2 Organic and Healthy Meat

Organic chicken meat is designed to have higher concentrations of omega-3 PUFA tocopherol (vitamin E) when compared to conventional meat and contributes significantly to human health by reducing risk of many diseases via its antioxidant activity [101–105].

Consumption of organic poultry meat has the following benefits:

- Decreased sodium concentration.
- Free of drugs, hormones, and antibiotics.
- Adding omega-3 PUFA to in vitro meat can improve a healthy status.
- Reduced exposure to fungicides and pesticides.
- Improved several nutrients (vitamins, carotenes, amino acids, etc.) in the body.
- Animals are not subjected to some types of stresses.
- No animal suffering.

Omega-3 fatty acids found in fish oil play a critical role in development and improvement of function of the nervous and reproductive systems, improve vision, lower mild hypertension and risk of CVD, as well as prevent some cardiac arrhythmia, reduce the risk of diabetes, and alleviate rheumatoid arthritis symptoms [106]. The benefits of omega-3 PUFA in the body are as follows:

- Reducing inflammation symptoms.
- Enhancing the efficacy of immune response.
- Lowering risk of gut cancers and supports cancer patients.
- Improving the bile production due to efficient digestion.
- Minimizing the blood content of cholesterol, LDL cholesterol, and triglyceride.
- Reducing/preventing premature birth.
- Improving function of the retina.
- Lowering blood pressure and reducing allergic diseases.
- Omega-3 PUFA supplementation to diet prevents diabetes.

Oils extracted from fish exert inhibitory effects on secretion and synthesis of hepatic triacylglycerol, postprandial lipemia, very low-density lipoprotein (VLDL), and platelet aggregation and stimulatory activities upon circulating HDL cholesterol, thereby preventing CVD [85, 107]. On the other hand, the inclusion of selenium in broiler diets led to an increase of LNA and total omega-3 PUFA ($P < 0.05$) and a decrease of thiobarbituric acid-reactive substances in thigh muscle tissue of chickens [108]. In the same study, supplemental selenium at the level of 0.5 mg/kg lowered lipid oxidation in muscle tissue of thighs stored at -20°C for 28 days or in muscle tissue of fresh thighs. The inclusion of linseed oil in broiler diets with organic selenium (0.5 mg/kg) can enrich tissue meat with selenium (from 0.511 to 1.071 mg/kg DM), as well as improve percent of total n-3 PUFA from 5.27% to 6.25%. Where n-3 PUFA and selenium are nutricines, produced chicken meat may be considered as functional and healthy foods [108].

5 Conclusion and Health Perspective

Poultry diet is a major component of an overall lifestyle that can have a significant effect on human health. Livestock systems range from farms of cattle and sheep in the grassland areas to mixed livestock systems including sheep, cattle, goat, swine, and poultry of a range of strains and breeds and of different sizes of the flock. Due to this variation, nutritional strategies that aim to obtain 100% organic feed through the given time scale need to be tightly related to the farm position and cannot be based on blueprint recommendations. The analysis of home-grown feed ingredients and accurate calculations of diet nutrients according to the nutritional requirements in the different phases of age are important to improve the efficiency of diets. The use of genetically modified foods is one of the most promising biotechnological applications. The organic or functional foods produced by genetic manipulations will have a significant role in animal and poultry production, agriculture, medicinal aspects, and society as well. The organic foods of poultry origin may only include organic eggs and organic chickens.

6 Recommendations

To produce organic/healthy products, it is important to study the available and sustainable nutritional strategies and evaluate knowledge-based alternatives of growth-enhancers as well as develop more effective models and protocols for quantification of the bioavailability and bio-accessibility of bioactive compounds for health studies in animal and human. Despite these promising features, consumers cannot easily accept the recent changes especially those of transgenic nature so that the health benefits of organic poultry products (eggs and meat) should be investigated well based on accurate scientific studies. The development of poultry production and industry is not only depending on producing a large number of eggs and a large amount of meat but also on producing more health products.

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Ways to Minimize Nitrogen Emissions in Agricultural Farms

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Abstract The overwhelming scientific unanimity is that gases produced by a different agricultural system including poultry farms are affecting the climate of the globe. One of the ecological defiances is poultry manure elimination and/or utilization. Chicken manure and its nitrogenous compounds could be a prospective pollutant rising eutrophication, nitrite or nitrate impurity of water, acid precipitation in the air, and ammonia volatilization. Thus, lowering nitrogen excretion in fowl litter is necessary to keep an immaculate environment. Appropriate nutrition is a significant first step to optimize growth and performance in animals and to lower the negative effects on the environment. Amino acids are components of fowl nutrition that largely affect animal growth. However, deficient or surplus amino acid supplementations in diets elevate nitrogen emission. One way to lower this emission is to prohibit uricase vigor in the microflora in chicken manure. Egg yolk antibodies are economic alternates for supplementation in the diets of chickens. Administration of feed grade antibodies into poultry feed could be a probable program to reduce bacterial uricase action and minimize ammonia excretion from chicken manure. To utilize this dietary strategy efficiently, a well-balanced ration formulation and a more feasible method of delivering the antibodies in feeds need to be improved.

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Contents

1 Introduction

Due to the increment of common apprehension regarding the ecology, agriculture has been searching for methods to remove, lower, or grip hazardous materials found in manure [1, 2]. A lot of environmental confrontations related to manure elimination has to face the chicken's manufacturer, such as in the USA, that the production of litter and poultry manure is higher than 13 billion kg per year [3–5]. The large amounts of plant nutrients in poultry manure elect it to be a suitable fertilizer. The percentage of phosphorous and dietary nitrogen from the feed intakes which are excreted in poultry manure is 57% and 50%, respectively [6]. Moreover, the excretion of commercial White Leghorn hens is nearly 70% of phosphorous and 65% of nitrogen of diet contents [7]. Both of nitrogen and phosphorous caused significant environmental pollution influencing the quality of different water sources.

The hazardous environmental troubles related to poultry manure comprise surface spreading of pollutants and ammonia gas (NH_3) volatilization that leads to the acid precipitation increment in the air. NH_3 volatilization in poultry manure may give rise to health problems for human, eutrophication in water sources, and air pollution [5]. The air waste the most of the NH_3 produced from poultry manure, while the litter holds a considerable amount in the poultry house [5]. NH_3 could volatilize more than 50% of chicken manure nitrogen [8]. Moreover, it was observed that 40% of feed nitrogen is lost to the air [7].

The accumulation of ammonia in the atmosphere of poultry houses lowers resistance to different diseases, growth performance, immune responses, and egg production [9–13]. The influences of various ammonia concentrations in the atmosphere were assessed at relative humidity and elevated temperature on the thermoregulation and performance in broiler chickens [13]. These authors reported the significant lowering in feed intake and body weight by the elevation of atmospheric

NH_3 concentrations from 16 to 54 ppm and that the minimum NH_3 concentration qualified broiler chickens for keeping their body temperature in comparison to broiler chickens exposed to higher concentrations of NH_3. So, the authors interpreted that thermoregulation and growth performance of broiler chickens are significantly affected by atmospheric ammonia. The influences of various atmospheric ammonia concentrations (0, 25, 50, and 75 ppm) were investigated on growth performance of broiler chickens [10]. The 50 and 75 ppm levels of ammonia significantly decreased the body weight at the 7th week of age compared to 0 ppm, and the 75 ppm atmospheric ammonia level elevated mortality (13.9%) markedly versus to the 0 ppm level (5.8%). The authors proved that ammonia is ferocious to broiler chickens regarding their growth performance. Furthermore, atmospheric NH_3 lowered immune responses [12]. Both feed efficiency and body weight of broiler chickens were extremely lowered at the exposure of 52 ppm atmospheric ammonia. Moreover, when broiler chickens housed in 26 or 52 ppm atmospheric ammonia, the hemagglutination inhibition antibody titer (HI) for Newcastle disease virus (NDV) markedly decreased. So, lowering ammonia volatilization in the atmosphere is necessary for taking care growth performance and animal health. Though various strategies have been proposed to produce an antibody (IgY), specific to uricase enzyme produced in egg yolk, and to decrease ammonia volatilization in poultry manure, represent a probable strategy. So, the main concept of this chapter is the argument of the deactivation strategies of microbial uricase action by an immunoglobulin (IgY) produced in egg yolk and specific to microbial uricase which leads to lowering of NH_3 volatilization in poultry manure [12].

2 Types of Agriculture Farms

Agriculture farms involve farms of the broiler, layers, water fowls (duck and gees), quail, rabbits, and turkey. Broilers and laying hens can be housed in wired cages stacked above each other. The feces store below the cages or onto a conveyor belt which transfers the manure to external storage of dry solid manure [14].

3 Sources and Mechanism of Ammonia Emission

The decomposed uric acid in the poultry manure is the main source of total ammoniacal nitrogen (TAN). Uric acid is hydrolyzed to urea then to TAN. Storage conditions such as temperature and water content of the manure control the concentration of TAN [14]. The storage of the poultry manure could be stored as slurry after addition of water or dry on the floor. Many changes may be occurred during storage due to NH3 volatilization [15]. In most countries, the storage of manure for a month leads to hydrolyzing of all excreted area to TAN. Zhang and Day [16] observed a little transformation of organic N during storage of slurry. The concentration of TAN in poultry manure is more changeable than others because of the affection of storage conditions on the slow hydrolysis of uric acid [17].

The decomposition of products such as feathers, manure, bedding, and dust occurs under two various conditions according to two oxygen requirements that are anaerobic and aerobic conditions. Organic sulfide, mercaptans, and hydrogen sulfide are produced from the degradation of sulfide-containing compounds. Also, amines, ammonia, skatole, and indole are produced from the destruction of nitrogen-containing compounds. Moreover, degradation of other compounds results in the production of aldehydes, alcohols, and volatile fatty acids which are considered as odorous compounds. The aerobic biodegradation leads to the production of odorous compounds containing nitrogen that resulted from degradation of nitrogen-containing compounds, while the anaerobic biodegradation leads to the production of odorous compounds containing sulfide [18]. During the solid and liquid phases of manure, biological degradation of organic material produces odorous compounds. The concentration difference between solid/liquid and gas phases controls the odorous compound volatilization rate. Concentration in the gas phase is affected significantly by temperature and ventilation rate. The lower the volatilization rates, the lower the ventilation rates and vice versa [18]. The formation of other odorous gases will increase with increasing moisture content in the litter which activates anaerobic bacterial. Moreover, high pH (>7.5) causes aerobic conditions, which lead to decreasing odor emission rates.

4 Ways to Minimize Ammonia Volatilization from the Excreta of Poultry

Figure 1 shows several ways for minimizing nitrogen emission in poultry farms. The microbial action promotes the operation of ammonia volatilization. The aerobic degradation of uric acid has five enzymatic steps [19]. The first step is the conversion of uric acid into allantoin by microbial uricase in poultry manure. Then, allantoinase changes allantoin into allantoic acid. After that, allantoate amidohydrolase converts allantoic acid into ureidoglycolate, and then ureidoglycolase changes ureidoglycolate into glyoxylate and urea. Lastly, urease hydrolyzes urea into ammonia and carbon dioxide. The deactivation of microbial enzymes could be a perfect instrument to prevent the NH_3 emissions from poultry manure. The equilibrium between ammonia (NH_3) and ammonium ion (NH_4^+) is regulated by pH after the generation of ammonia by microbial processes [20]. After the elevation of manure pH, the ammonium ion is converted into NH_3 gas and volatilized to the atmosphere [5]. Therefore, it is possible to lower the release of ammonia from poultry manure by transformation of ammonia to another non-volatilized chemical form. Deactivation of the essential enzymes in uric acid degradation series that can be made by making immunoglobulins specific to the important microbial enzymes is the necessary step for decreasing ammonia volatilization [12].

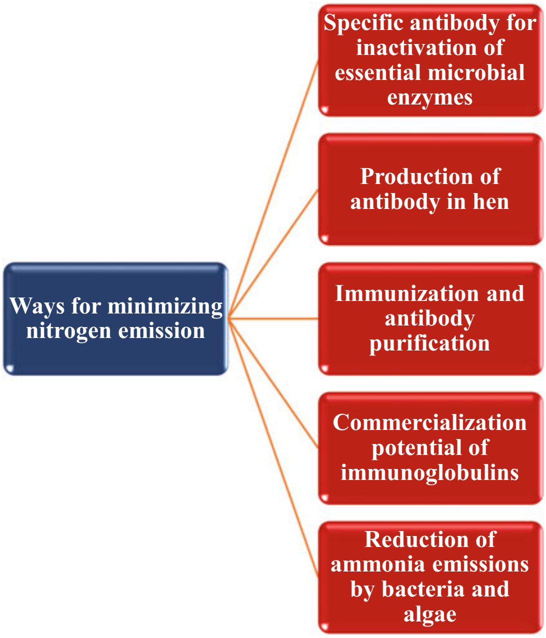

Fig. 1 Ways for minimizing nitrogen emission

4.1 Specific Antibody for Inactivation of Essential Microbial Enzymes

Many recent types of research have reported that it is useful to use antibodies for inactivation of microbial enzymatic action in animal manure. The use of immunoglobulins in pigs, poultry, or rats against urease was useful in growth promotion [21, 22]. The generation of ammonia in the gastrointestinal tract by microbial urease acts as a detrimental factor that leads to decreasing growth performance [22]. Predominately, better body weight could be obtained in urease-immunized animals. It was reported that the immunization of chicks and rats against crystalline jack bean urease resulted in a significant weight compared to control [22]. Therefore, authors suggested that the immunoglobulin specific to urease lowered ammonia output in the gastrointestinal tract by inactivating the action of microbial urease.

Similarly, these immunoglobulins possess the ability to frustrate uricase action in poultry excreta and lower NH_3 volatilization. There are many methods to use an uricase-specific antibody, comprising direct handling of poultry excreta with the antibody, addition of the antibody as a feed additive, or direct uricase immunization of birds. Selecting the method suits better relays on many factors. Initial factors that affect selection are the availability of specific immunoglobulins in addition to the economics of immunoglobulins large production. Also, the arrival of the prepared antibody to the suitable site must be managed. Immunization of the birds is an important indicator of the intestine level, but it does not confirm the bacterial deactivation in the excreta. The inclusion of antibodies in the diet fixes these issues by the primary decrease of microbial action in the chicken and probable suppression of uricase action in the manure [19].

4.2 Production of Antibody in Hen

The types of an antibody produced by research laboratories are mammalian polyclonal and monoclonal antibodies. Mostly, rabbits have been utilized to produce the working immunoglobulins. However, recently, the production of specific immunoglobulins by egg yolk is progressively drawing the attention of the scientists [23].

Avian immunoglobulins have been identified many decades ago and show many biochemical benefits more than mammalian antibodies. These benefits are because of phylogenetic variations between mammalian and avian species and can lead to elevated sensitivity and a minimized background in immunological assays [24]. IgY is a leading antibody from reptiles, amphibians, and birds. Amazingly, it does not stimulate the mammalian complement system or link to proteins G and A or mammalian rheumatoid factors. Also, it possesses a great yield and is slick to extract and purify [25]. IgY has a big role in the humoral immunity of skin surfaces and tissue through agglutination and precipitation of antigens [26].

4.3 Immunization and Antibody Purification

Many investigations mentioned that chickens are a stellar model for making specific antibodies against various protein origins. As the production of antisera is costly, the existence of IgY in the egg has driven various investigator to suggest chicken egg yolk immunoglobulins as an alternate source of diagnostic polyclonal antibodies [27]. Six laying hens at 22nd- to 24th-week-old were immunized with a proliferating cell nuclear antigen [28]. It was found that 20 to 30 μg of the antigen were sufficient to make specific polyclonal antibodies 20 day after immunization. Plateau antibody levels in the egg were attained after 30 day and stabilized at elevated levels to 81 day. One chicken made nearly 4 g of antibodies and 30 mg of specific antibodies separated from 62 eggs.

Chicken immunoglobulin production makes many advantages related to the health of the immunized animals. After immunization, the specific immunoglobulins are transferred to the egg yolk, from which the IgY then can be simply and rapidly isolated without immolation of chickens. IgY production is a major progress which should be treated as a perfect alternative to traditional polyclonal antibody production in mammals [29]. In addition to these benefits, IgY has been openly utilized in functional food, animal science, and bioproducts as well as an efficient application for treatment and prevention of diseases [25].

Immunization occurred through an intravenous (IV), intraperitoneal (IP), and intramuscular (IM) administrations. IV and IP give the quicker titer with the peak immunity within 7 and 9 days succeeded by a falling their titers until lower levels are reached on the 28th day. The booster dose is not effective compared to the first one although IM inoculation displays a rise in antibody titer if there is a booster dose on the 28th day [30]. Furthermore, perfecting the performance of the antigens and optimizing immunization protocols will make IgY more efficient and suitable for research and field applications [23].

The whole egg yolk may be used as an immunoglobulin source, but its high-fat content may interfere with their action [24]. So, immunoglobulins are commonly refined through different purgation methods [24, 30–32].

There are many benefits of egg yolk polyclonal immunoglobulins more than other origins. They can be acquired daily without immolation [33]. Furthermore, high efficiency in producing the high concentrations of IgY produced by one chicken per year (between 30 and 40 g in total) [23].

4.4 Commercialization Potential of Immunoglobulins

The laying hen produces about 15 ml of antibodies holding identical antibody concentration and reactivity to serum immunoglobulins [34]; this is equal to nearly 100 ml of serum per week. If every egg yolk gave 10 ml of a clarified antibody, and 100 μl of a 100-fold dilution of this preparation is necessary for every reactant well in a standard enzyme-linked immunosorbent assay (ELISA), then 1 egg would provide enough antibodies for 10,000 wells [35]. The immunized rabbit versus an immunized chicken gives approximately 20 ml whole blood per week [24]. Moreover, if the time needed to produce the requested antibodies, the daily cost of care and feed, and the initial cost of the animal are put into consideration, the cost of handling and feeding is more for rabbits than hens [24]. Rabbits are only beneficial at peak antibody generation, so the collection of all blood to the point of death is only at their titer peak. Eggs supply a persistent peak of antibodies for up to 200 days after inoculation [30]. The potential of refining large amounts of antibodies is of special concern, for oral administration of specific antibodies to avoid bacterial infections [24]. Egg antibodies can be used for structure determination and disease determination as efficiently as mammalian antibodies [30]. Eggs have been respectable to be efficient as passive antibody origins when utilized in a precautionary style [30]. Lately, oral administration of egg yolk antibodies was utilized successfully to block *Escherichia coli* infections in rabbits [36] and pigs [37], rotavirus infections in mice [38], and caries in rats [39].

4.5 Reduction of Ammonia Emissions by Beneficial Microorganisms

Livestock manure (LM) is used as an organic fertilizer in agricultural activities due to its contents of nitrogen, phosphorus, and potassium [40]. However, its excessive application may cause serious environmental problems such as eutrophication, air pollution, greenhouse gas emissions, and the spread of pathogens [41]. Biodegradation of organic matter in poultry manure is high compared to other LM. Serious environmental problems can be faced through unmanaged poultry wastes and/or their inappropriate land applications. While ammonia and greenhouse gases (GHG) emitting from waste storage facilities can pose a threat to air quality control mechanisms [42], nitrogen and phosphorus contamination can lead to eutrophication of surface waters and consequently pollute soil and groundwater [43]. In this regard, reduction of nitrogen compounds from poultry is crucial to reduce its adverse effects on the environment. Farmers should use the technological advances and the best practices to secure the environment. The effect on the ecosystems can result from the direct release of detrimental components into the surrounding atmosphere or the deposition of these materials into the groundwater. From another side, the environment in poultry houses is a combination of several biological and physical factors. In the modern poultry barns, high stocking density may reduce air quality. Air may contain high concentrations of both inorganic and organic pathogens, dust, and harmful gases such as nitrous oxide, ammonia, hydrogen sulfide, methane, and carbon dioxide. Farmers and poultry keepers should use the best available techniques (BAT), such as phase feeding or air washers, to minimize the emissions into the environment [43].

4.5.1 Bacteria

Increased bacterial fermentation of the dietary fiber in the intestine produces acetate, butyrate, and propionate fatty acids, which decrease the pH of the manure. The lower pH shifts develop more ammonium ion (NH_4^+). Several enteric bacteria play a key role in the reduction of nitrate to ammonia; however, its importance has been little studied for different commensal bacteria [44]. The existence of 5 mM nitrate supports the growth and induces ammonia and nitrite generation in *L. plantarum* and *E. coli* bacteria which grown at oxygen concentrations like that of the gastrointestinal tract. Ammonia and nitrite accumulated in the growth medium when at least 2.5 mM nitrate was present. Time-course curves confirm that nitrate is firstly converted to nitrite and then to ammonia. Strains of *B. longum infantis*, *L. acidophilus*, and *L. rhamnosus* which grown with nitrate gave slight changes in ammonia or nitrite levels in the cultures. Since it was supplied with exogenous nitrite, NO gas was produced readily independently of the added nitrate. Lactic acid production from bacteria causes medium acidification that in turn generates NO by nonenzymatic nitrite decline. Contradictory, nitrite was converted to NO by *E. coli* cultures even at neutral pH. Tiso and Schechter [44] suggested that bacterial nitrate decline to ammonia and the related NO formation in the gut could be an essential pathway of NO/nitrite/nitrate metabolism and there is no other way to link microbiome with health and diet.

When water purification systems are applied in chicken farms, the water purification system was effective in removing iron and other contaminants from good water. Thus, the visible biofilms were not observed on pipes and membranes in these systems. Animals fed with the treated water showed the reduced occurrence of infections by enteric bacteria among animals in these farms. In one chicken farm in Canada, the loss of birds reduced from 3–5% to 0.5–2% annually due to infections after installing the water purification system [44]. It was reported that application of water purification system resulted in improvement of feed conversion by 14% and reduction of indoor ammonia concentration from 60 ppm to 2 ppm. Moreover, the increment of uric acid in the manure is 2.2 times. A reduction in the ratio of anaerobes to aerobes was found in manure sample. Furthermore, feeding of treated water led to decreasing of uric acid used by bacteria in comparison to feeding with good water. Also, a change of gut microbial load by using functional gene analysis and DNA pyrosequencing was observed. Improvement of water resulted in a reduction of urease gene expression and an increment of gdh gene [44].

4.5.2 Algae

Phytogenic feed additives were used as growth promoters for many years in addition to their effective role in the reduction of ammonia gas emissions. The modes of action to reduce NH_3 emission include direct binding of NH_3 [45]. Bio-alginates are successfully applied in human and veterinary medicine. The interesting thing is the ability of these bio-alginates to absorb catabolic gases, particularly NH_3, which is produced during digestion and conversion of nitrogen compounds [46]. Hydrolyzed brown algae (*Ascophyllum nodosum*) are prepared to follow the line of plant products from algae. The hydrolyzed marine brown algae *A. nodosum* recommended by Čermák et al. [47] are added into the pelleted feed (injection during pelleting) or into the drinking water of broilers. They observed selected physical and chemical parameters and parameters related to fattening and zoo sanitary state. In the first phase, the preparation was injected into pelleted feed mix. Hydrolyzed marine brown algae *A. nodosum* were added from the very beginning of the fattening in the following ratio: 400 $g.t^{-1}$ of a feed mixture (instead of the same amount of wheat). The second phase consisted of two trials in which the hydrolyzed preparation was added in fixed concentrations (1:1,400–600 or 1:1,600–1,700) into drinking water. The results show a positive influence on production hall environment. The concentration of NH_3 in the trial hall was no significantly lower than in the control hall. The treated broiler chickens decreased the mortality about 1.8% [47].

5 Conclusions

High ammonia and nitrogen compound concentrations in poultry houses can have negative impacts on growth and productive performance and health aspects of birds, particularly in the winter season when ventilation is controlled tightly. Several nutritional, managerial, and microbiological ways could be followed to cope with these harmful emissions within environmentally friendly conditions.

6 Recommendations

Appropriate nutrition is a significant first step to reduce nitrogen emission. Deficient in surplus amino acid in should be avoided. Another way to lower this emission is to prohibit uricase vigor in the microflora in the manure. The administration of feed grade antibodies into poultry feed could be a probable program to decline bacterial uricase action and reduce ammonia excretion.

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Part V
Policies and Conclusions

Policies That Work for Sustainable Agriculture in Egypt

Moataz Elnemr

Abstract Sustainable agriculture is economically, environmentally, and technically viable. Sustainable agriculture has different practices than traditional. Policies should be designed and planned to serve the goals of sustainable agriculture. Policies have to consider the local Egyptian environment and properties. There is a need for a framework lead to create a national policy for sustainable agriculture. Sustainable agriculture planning should be in participatory way not in sectorial level. Farmers are essential in planning for sustainability as they are the source of the research and extension needs, and they are mainly concerned by implementing sustainable agriculture practices. Policies will be created depending on three main considerations acting sustainable agriculture elements that need to be integrated: reforming external institutions and professional approach, supporting local groups for community action, and supporting resource-conserving technologies and practices. There is a need for a framework of policies to attract investments to the agricultural sector. Application of these policies requires suitable implementation mechanisms and pack of laws and regulations. Promising impacts are expected to increase production and reach self-sufficiency from applying sustainable agriculture practices and supportive policies.

This chapter suggests 22 policies that are suitable for the Egyptian agricultural sector to support transition to sustainable agriculture and self-reliance. It is recommended to monitor and evaluate the impacts of such policies to clarify the needs of modifications or replanning.

Keywords Agriculture, Egypt, Policies, Sustainable agriculture, Working policies

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Contents

Abbreviations

ABE	Agricultural Bank of Egypt
GDP	Gross domestic products
IPM	Integrated pest management
IT	Information technology
L.E	Egyptian pound = 0.06 United States Dollar
MALR	Egyptian Ministry of Agriculture and Land Reclamation
NGOs	Nongovernmental organizations
NRA	Nominal rate of assistance
STDF	Science and Technology Development Fund in Egypt

1 Policies Framework and Creating National Policy for Sustainable Agriculture

1.1 Policies Framework

The chapter titled "Applicability of Sustainable Agriculture in Egypt" in volume I showed that sustainable agriculture in Egypt is achievable. It is still necessary to coordinate between all sustainable agriculture elements and system actors. This coordination is direct responsibility to the governments who make policies to encourage transition to sustainable agriculture and embrace its required actions. Without policy support sustainable agriculture achievement is going away or may be impossible.

Sustainability is not luxury anymore; it is the right of next generations to get their benefits from resources. Lack of resources is no longer acceptable explanation for why Egypt is still far from sustainability. There is a lot to do with available resources. If we want to reach sustainability in the agricultural sector, we should know that we may be in a try to manage unmanageable [1].

It is a governmental responsibility to make policies and suitable mechanisms to follow up the implementation process. Government is the only entity which can collect all the required information, system actors, and involved institutions in one group and put all of them face to face in front of their responsibilities. Agricultural policies generally prioritize adaptation of more sustainable use of resources and protecting farmers against the impacts of extreme events [2].

Successful policy set needs a right start point. A suggested start point will be in the answer of the question about how policies can address sustainable agriculture issues. The answer will be found when policy makers are aware and consider the following points:

1. Unique nature of sustainable agriculture including definition and goals.
2. Sustainable agriculture concept is complex, not related to single issue or specific work group.
3. The concept is contested and can vary according to the view of actors.
4. There is a need to have a clear answer about what should be sustained, for how long, in what are, for whose benefits, and how can you measure accessing to success or not.
5. Facing the fact that answering the previously listed questions is not easy and needs scrupulousness among huge database.
6. Sustainable agriculture is not a set of practices limited to certain time or place.
7. Policy should consider internal and external changes not just enabling conditions to adapt technologies.
8. Learning from previous policy mistakes.

It can be said that policies support for Egyptian agricultural sector in Egypt has negative effect on the returns of the farmers. The nominal rate of assistance (NRA) is an indicator that describes the percentage by which government policies have raised or lowered gross returns to farmers above what they would be without the government's intervention [3]. This indicator has fallen dramatically for Egypt through the last three decades. It was 23.72 during the 1980s to reach −1.05 during the 1990s and then fell to −5.50 by the end of 2005 [4]. Negative number indicates that government intervention has lowered the returns of farmers. This gives an indicator about the absence of planning and following mechanisms and maybe absence of policy applications which will not exceed to be recommendations in this case.

Policy makers should not consider the variation of view for the agricultural problem between farmers as an obstacle for sustainable agriculture. This is the nature of things in sustainable system. All of these views should be considered to be studied and filtered to reach the most satisfactory solution for all the actors. Maybe it looks hard but the good news is that beneficiaries will be wider to include the whole community. Also the view to the farmers as mismanagers of natural resources has to change. Training and improving skills supported by strong extension system are the ways to define farmers what is really needed from them and make them real participants in development process.

It should be known also that sustainable agriculture solutions should be technically, economically, ecologically, and socially approved. Excluding any of the previous considerations makes any solution useless and unworkable.

This chapter tends to suggest policies that can work to achieve sustainable agriculture in the Egyptian environment to be considered for improving livestock, fisheries, and crop production.

These policies will draw the framework of a general sustainable agricultural policy. These policies will be based on reforming external institutions and professional approach, empowering local groups and community action, and encouraging resource-conserving technologies and practices [5].

1.2 Creating a National Policy for Sustainable Agriculture

Agricultural growth is required to increase the power of poverty reduction [6, 7] and reduce the gap between people needs and agricultural production. Coordinating policy and institution work in a clear way is the first step that government can take.

As mentioned before, policies should start from local farmers' need. Being far from communicating with farmers encourages them to keep depending on external resources as it is the only way they know to keep having returns. These resources are more costly and have negative effect on the environment.

Using an experience or a policy cited from another country is useless. The issue here is not the farmer but the total structure of the Egyptian farmer personality including beliefs, skills, knowledge, and ability to accept modern or transferred technology. Also policies must depend on the availability and nature of the local resources. The dialogues between actors are required as they give fast reactions and feedbacks that are useful in giving elasticity for policies and make it always near to the real situation. Policy makers can then concentrate on enabling actors to make the efficient use of resources whether natural, external, and social resources.

Policies should protect the farmers against expected risks they may face. Expected risks can result from the following [8]:

1. Market and prices: Sources of risks related to marketing and pricing are changes in price of land, new requirements from food industry like improved product specifications, changes in input/output prices due to shocks, trade policy, new markets, endogenous variability, exchange rates, etc.
2. Production: The risks include personal illness which may prevent farmers to make effort. Natural disasters (flood, landslides, pollution, droughts, hail, frost, pests, contagious diseases), obstacles for using technology, etc.
3. Financial: If the income expected from another resource is higher than the expected from farming, farmers may turn to the other activity. Also the change in interest value and possibility of accessing credits are threats for farming activity.
4. Institutional/legal: Risks here are related to the change in policies, regulations, and laws on short term.

National policy of sustainable agriculture should be supported by a mechanism of insurance to protect farmers against the previously mentioned risks to reduce the fear of losing their only income source without coverage. The created national policy should be announced, and this point is missing in all the strategies created to reach sustainable agriculture in Egypt [9].

Even with right planning and strategies with suitable implementation mechanisms, we will lose the two of the main conditions of agricultural sustainability which are integration between sustainable agriculture elements and interaction between the actors. Declaring national policy of sustainable agriculture will value the societal goals and needs in addition to raising the profile of sustainable agriculture practices and the policy making process itself.

The national policy of sustainable agriculture is considered to work on achieving and supporting national goals of all sectors like unemployment reduction by creating job opportunities, improving national income growth rates, raising income level, and promoting exports. Also this policy should focus on achieving self-sufficiency of most agricultural products especially strategic, reaching efficient use of energy and natural resources in addition to encouraging farmers to interact with the new needs and plans and also encouraging investments in the agricultural sector and sustainable practices, and enhancing research in agriculture.

Continuous monitoring of the effect of these policies on the agricultural sector as a whole should be done [2]. All the elements of agricultural production containing crops, livestock, poultry, and fisheries beside the situation of resource consumption have to be periodically evaluated to deal with any mismanagement practices or wrong policy application. Databases are essential for such purpose; at the same time costs and efforts required to do this process should not be considered an obstacle and must be provided.

2 Reforming External Institutions and Professional Approaches

For many years, institutional role in agriculture was neglected as the development of agricultural sector plans focused on increasing the crop production to increase food supplies. The structure of organizations improves the ability of countries to fight poverty and how can the agricultural sector be important by its contribution in the GDP [10]. Institutions whether the government or nongovernment are responsible for linking between actors, coordinating between processes, and creating and setting teaching and training programs. The main problem of external institutions is that it may be organized in sectorial level. This causes loosing linkage between farmers and professionals. Policies suggested in this section aim to widen effect for institutions in the process of developing the agricultural sector in a sustainable way.

2.1 Policy 2.1: Formal Adoption of Participatory Methods and Processes

Organizations in most cases do not participate with farmers. This is not only related to the policy and regulations of an organization; trained agents and professionals who belong to any organization are still few to assure the quality of the communication with farmers and the aimed beneficiaries.

In many cases, methodology to do this is also missing. Formal adoption for these methodologies gives support to wider participation between farmers, researchers, extensionists, and planners. Two main points have to be considered when converting participatory methods into formal. First one is the incentives for all involved people to make them familiar with the process. Second is the gradual conversion to the formal way because when it is too rapid and out of simplism, methodologies will be unable to suit different institutional conditions.

2.2 Policy 2.2: Enabling Information Systems to Link Farmers with Professionals

Information system is an essential requirement for sustainable agriculture farming system. As mentioned before, linkage between agencies and professionals with farmers is needed for research and extension process.

In Egypt information system creation will be more complex. The high ratio of illiteracy between Egyptian farmers makes them unable to get benefits from any information system. For example, the MALR created an online extension system called “Vercon” that has information about crop, poultry, and fish production. Maybe the system is well designed and continuously updated, but how will it be possible for a farmer who can't read and write to reach his required information or analyze it even if he got help to find it. In addition, the low economic level of farmers does not allow them to get the opportunity of holding personal computers beside the limited electric load in most of Egyptian country which increases difficulties of depending on IT systems.

IT-based information systems may not be suitable for Egyptian farmers in the current time period, but there is no doubt it is still necessary to provide extensionists and researchers with huge databases. Farmer to farmer extension system introduces an acceptable solution for the Egyptian conditions. This system enables farmer to interact directly with each other and exchange their knowledge and experiences. One of strength points of this system in Egypt is that the Egyptian farmers already have a high credit of experiences which resulted from practicing agriculture activity for thousands of years. Of course all of these experiences need improvement, but their existence makes it easier to exchange information and complete knowledge building.

Enabling well-trained extensionists to communicate directly with farmers increases the efficiency of information system. The meaning here is that the field should be the playground of linkage between farmers, extensionists, and researcher to ensure that capacity building and training occurs. In this case farmers will do their role for creating research demand and sharing in the extension system.

2.3 Policy 2.3: Building Suitable Project Culture

Projects can serve better in sustainable agricultural system if it made learning process rather than relying on a scheme. Technologies that are easy to teach are preferable to be tested under local conditions. Agricultural project proposal should focus on the priorities of farmers and urgent issues. There is no need to make the projects high technical or over-innovative despite the high value of this direction.

Targets of projects have to access farmers' minds in a fast and clear way. Low-risk projects also encourage donators and investors to start supporting sustainable agricultural projects. We should put in our minds that projects have to start from local people with a continuous communication with farmers to get feedback during the project cycle to plan and replan.

2.4 Policy 2.4: NGO Scale-Up

NGOs work in small scale if compared to governmental organization. NGOs often tend to work on small scale to avoid the risk of monetary losses. NGOs that work in the Egyptian agricultural sector are not widely known. This means that they have no clear role or significant effect on the agricultural development, maybe because of their own strategy or poor planning. The issue here is how we can encourage NGOs to scale up and play a greater role.

It is assumed that NGOs have qualitative work and may have the fear to become hierarchical and bureaucratized [11]. Forcing the capacity of NGOs to scale up may come from partnership with governmental and other nongovernmental organizations. Governmental organizations have to consider decentralization in their plans and flexibility in their operations to give opportunity for NGOs to be a part of the governmental system. NGOs can train the staff of governmental organizations as one of the participatory shapes between organizations. It may look easy but in most cases NGOs suffer from lack of training experience. NGOs may suffer also from limited financial and management experience, limited coverage, lack of technical capacity, and lack of communication and coordination with other organizations. The previously mentioned issues reflect the need of scale-up for NGOs and the importance of partnership with governmental organizations.

Egyptian governmental organizations have the advantages of wide coverage, ability of communication with people and other organizations, experienced professionals in different agricultural sectors, and an acceptable financing ability.

The question which may appear here is: why governmental organizations may need NGOs if they already have these advantages? Governmental organizations are heavily loaded with agricultural development duties; so NGOs will play an important role in relaxing governmental institutions. NGOs can also act as a channel to convey financial resources, information, and technical resources from governmental and community-based organizations. When this participation occurs, NGOs are able to scale up and have exchangeable support with governmental organizations.

2.5 Policy 2.6: Reform Teaching and Training Institutions

Sustainable agriculture concept is related to learn how things can be done in our environment. Egypt has about 21 faculties of agriculture and specific agriculture faculties. Beside this there are technical schools almost in all cities. Of course this number is supposed to cover the agriculture labor market needs of professionals and technicians in all specialists.

Despite the huge number of agriculture educational institutions, they did not make the required effect on agricultural development. This issue may be explained when discussing the terms teaching and learning. Learning is not a normal result of teaching. If teaching materials and contents are not designed to meet the community needs, the product of this educational system will not be able to deal with the problems of his environment.

All actors in the agricultural sector are important in learning process, while educational institutions in Egypt give the priority to the teaching process regardless of its return on the local agricultural system. It is essential that farmers, trainers, extensionists, researchers, teachers, and administrators are responsible to communicate and link to create the required relationship between them to transfer knowledge. All of those actors can teach each other.

The role of institutions here is creating the suitable learning environment where learning can be through publications, research, and personal experience including experiments and explorations. This environment will permit transition from teaching to learning style which has deep implications. One of the benefits of this move is the self-strengthening for people and groups by self-learning. Institutions should support this approach and encourage facilitators to do such kind of training.

2.6 Policy 2.7: Creating Mechanisms of Participatory Planning

Sustainable agriculture needs cooperation between all actors. We have to reach agreement between all interested parties in policy making process. Policy makers tend to take decisions and draw wide lines of policies away from policy appliers and beneficiaries. At the same time community-led policies are stronger and more able to be applied. In this case a conflict of interest between policy makers and local people may appear.

There is a need for a kind of mediation between micro and macro levels. It can be done by neutral actors who look forward to consensus among all involved people in sustainable agriculture.

Creating a mechanism to exchange suggestions and opinions about sustainable agriculture may be a successful policy to serve sustainability purposes. In practice, policy makers still represent a lesser extent of the interests of the public. Policy makers should know that involving public on decision-making is a critical requirement for sustainable agriculture, and it does not threaten their power.

3 Supporting Local Groups for Community Action

Sustainable agriculture needs coordinated action between community parties. Farmers currently work alone on their own projects. Local institution and groups can play a good role in communicating farmers with each other and with the local institutions and organizations. This will enforce social and economic structure in the rural community.

The following paragraphs show suggested policies that will enable local groups to play their role in linking rural community parties.

3.1 Policy 3.1: Supporting the Role of Local Groups

The required actions for sustainable agriculture must be taken on group level. Interest in improving individual farmer skills, knowledge, and motivations is important, but it will not give beneficiaries if the work is still on personal level. Local groups will play the role to coordinate actions and link the farmers. Also they have the responsibility to clarify that sustainable agriculture practices are not financial resource consumer, but they tend to increase benefits identically with normal practices in a systematic way besides beneficiaries for the whole community. Local groups and institutions have six shapes (refer to Sect. 7.3 in the chapter titled "Applicability of Sustainable Agriculture in Egypt" in volume I showed that sustainable agriculture in Egypt is achievable). The interaction between local institutions and groups will form a community-based action which needs increased attention.

3.2 Policy 3.2: Partnership with Rural Community

Success of sustainable agriculture is directly related to the ability of making partnership between parties with conflicting interests. Community should be involved in decision-making. This involvement will be achieved by national trend to enable the community to do this action. It requires providing rural communities with suitable infrastructure of communication services. Interests' confliction between rural community, governmental organization, and different agencies will not be an obstacle towards their partnership when the public good is the target. Achievement of such partnership needs facilitating agencies supported by national plan of regulations and roles for their work.

3.3 Policy 3.3: Incentives for On-Farm Employment

The continuous decrease of male employment in Egyptian agricultural sector (World Bank statistics) gives an indicator on the lack of planning to encourage labor to work in agricultural activities. Male employment power in the Egyptian agricultural sector is considered the more skilled and experienced than female power. Turning to sustainable agriculture needs to embrace resource-conserving technologies which need more labor. In addition sustainable agriculture practices need continuous increase in labor skills and knowledge.

Workload in the field and required training will be hit by the weak salaries offered. The problem here is to create incentive schemes to encourage labor to join on-farm employments. It may require more financial support directly to famers in addition to improvement of the rural services to enhance rural community standard of living. Incentive scheme should be planned relying on social studies about causes of the leakage of labor from the agricultural sector and what alternative sectors or solutions they resort to.

3.4 Policy 3.4: Giving Ability to Groups to Access Grants

Farmers in Egypt are likely described as poor people. It has long been assumed that poor people cannot save money. Agriculture pattern in Egypt depends on external resources which need additional financial resources that farmer can't meet. Loans may be the solution for farmers in such cases. Little or no collaterals keep farmers away from dealing with banks because of the exchange expected risk. They may tend to get money from other resources which will make borrowing process described with randomization and may push farmers to more poverty when trying to pay their loans. Local groups when trusted can manage financial resources in a way that suits the needs of the farmers. They can also cover farmers' loan.

Because farmers are poor and have little or no collateral, they are too high a risk for banks and so have to turn to traditional money lenders. These inevitably charge extortionate rates of interest, and very often people get locked into even greater poverty while trying to pay off debts. The policy suggested to work here is to give local groups the opportunity to work with dedicated sector of banks for agricultural activities. It is known that banks are following general national economic policy, and this places agriculture in a relationship with other sectors that may attract it away of its development actions. ABE can play greater role if it designed its policies referring to the local conditions of the Egyptian agricultural sector, and it may hold local groups for more efficient communication and dealing policies with farmers to assure covering farmers' needs and paying loans back.

4 Adoption of Resource-Conserving Technologies and Practices

Resource-conserving practices are farm-combined practices that are compatible with biophysical and socioeconomic local conditions of farmers. Management practices and the technologies related to pest, nutrient, soil, and water are required to be integrated for reaching sustainable agriculture purposes.

Most of these practices introduce the low-external input options. Natural processes are used in such applications to use their outputs as inputs in another farming purpose. This way keeps farms productive in addition to reducing their environmental impact.

Resource-conserving technologies have two main functions. First is on conserving current on-farm resources like water, soil, nutrients, and predators. In addition they can make additions to these resources into the same system that may replace some of external resources. Water-harvesting technologies, nitrogen-fixing crops, or new predators are examples of these technologies. These technologies are featured by multifunctionality.

Their adoption will mean favorable synchronized changes in several elements of the farming system. For example, the trees that surround the farm to be used as windbreaks can encourage predators besides making their essential role to reduce soil erosion. Legumes are known by their ability to fix nitrogen as they can break a crop to delay or prevent the disease infection between crops. Grass contour strips can be ploughed in the soil as a green manure. They help to increase soil porosity in addition to reducing the speed of water runoff over soil surface in addition to their known role as livestock fodder. Increasing the number of applied resource-conserving technologies and link between them creates an integrated farm system which is an essential component of sustainable agricultural system.

The main obstacle which faces farmers to adopt resource-conserving technology is the required finance. They are required to reduce the use of fertilizers and pesticides while keeping their output to make their farming process more profitable. They may not be able to take the risk of testing new inputs and methodologies and waiting for success. The cost of these technologies can't go forever and it will be reduced gradually. The needs are policies that support this transition by investing labor, management skills, and knowledge.

Research is a main element to widen the applicability of such technologies and reduce expected short-term risks. The following sections discuss policies that may help and support the adoption of resource-conserving technologies and practices.

4.1 Policy 4.1: Raising Awareness of the Dangers of Natural Resources' Overconsumption

First step should be taken to protect natural resources from overconsumption as being convinced that the consumers of resources and their products are indispensable partners in planning and application of practices. Farmers should be informed and aware that natural resources are not regenerative by their nature. Overconsumption may lead to lose these resources or cause its nonexistence. This will lead the farmers to ask about the suitable practices they can follow to keep the resources. When reaching this, it can be said that farmers are on the beginning of the road to resource-conserving practices.

Another threat facing natural resource conservation in Egypt is the patterns of food consumption in the Egyptian community that are characterized by profusion. It is usual that people buy and cook more than real needs of food. Surplus food will go to the waste basket. In addition most of the consumption due to the low economic level for Egyptian families is based on subsidized commodities. This complex situation put additive load on the government because of the continuous need for areas that may be valid for culturing to accommodate the increasing quantities of food wastes and more finance to cover food subsidies.

What is required here is direct communication between government and consumers to convey the message about negative impacts and expected environmental and economic risks which may result through their practices and living patterns. This responsibility will be directed to media, extension system, and local groups. It should be considered also that creating an atmosphere of trust between government and mentioned consumers will give support to assisting entities to play highly efficient role in this mission.

4.2 Policy 4.2: Regulating the Use of Pesticides and Strategy for Integrated Pest Management

Pesticides as any product should be tested for using license and being registered. These tests prove the application validity of pesticides under certain conditions. Licensing and registering are not just related to the chemical itself but extend to spraying machines and equipment used during spraying process. Licensing and registering must be taken under local conditions. Pesticide effectiveness and environmental impacts vary from one place to another; by the meaning imported registered chemicals in another country may not be suitable for the Egyptian environment and have to be banned.

Farmers and labors should be well trained in using pesticides. Agricultural extensionists can play an important role for this purpose. These regulations have an economic impact on the farmer because of the assured quality of used pesticide which means less quantity of chemicals. Environmental and health beneficiaries are also expected because of the adjusted used amounts of pesticides and precautions taken during spraying process. We need a national code for pesticides and their using process as a whole.

In Egypt pest control goes in mind to the chemical resistance. When considering the economic and environmental impacts in pest control and management, practices which tend to suppress pest populations below injury level are called integrated pest management (IPM). IPM needs to link research and extension institutions to develop pest and predator management technologies. IPM practices are nonpolluting and sustainable. It requires training on crop monitoring in analytic way. All these required actions should be supported by the government to facilitate farmers' involvement in IPM process to reduce the inappropriate use of pesticides.

4.3 Policy 4.3: Development of Sustainable Agriculture Research

Research institutions have the responsibility of increasing research related to resource-conserving technologies and sustainable agriculture. Research proposals should be based on the problems cited from the farmers. Egyptian Ministry of Higher Education and National Research Center have different agreements for research fund on the local or international level.

The issue here is most funds are directed to highly innovative research or based on high technologies which in most cases lose the wide applicability under Egyptian farming conditions. Research impact assessment is required to improve significantly the role of research and innovation system and its contribution to address a wide range of socioeconomic and environmental issues besides increasing the efficiency with which public funds are used [12].

As mentioned before Egyptian farmers and agriculture labor are still in need to improve their skills and knowledge. The fact is farmers are the people who know their conditions best; so they should be involved in all research activities like design and implementation. Research should start in solving current problems and then being improved gradually for using modern technology. All research proposals should also cover and study the technical, economic, environmental, and social approval of the practices and applied technology. Despite the increase in research fund by creating STDF or signing agreements with foreign organizations and countries, the research fund is in continuous need to be increased to cover all the needs of the involved research organizations.

4.4 Policy 4.4: Establishing Greenbelt Mapping

It is required to increase cultivated land area to meet the increased needs of agricultural products. Population in Egypt is concentrated near to the River Nile. Cultivated area in Egypt is decreasing because of urban creep, and the situation ends with cultivated lands surrounded by buildings as a pocket. Small holding area turns the agricultural land into noneconomic units. Owners of the lands tend to build houses over these lands or use it in another activity hoping to increase their income. There is a need to start agricultural projects in areas that have promising opportunities like Sinai and West Desert to extend cultivated areas. This may attract people to settle in these areas as it will be characterized with job opportunities. What is needed here are:

1. Mapping a greenbelt of the current economic cultivated areas and proposed areas of reclamation after achieving necessary studies
2. Setting pack of laws to protect cultivated and proposed reclaimed lands against changing the agriculture activities

3. Starting new energy projects to provide new areas and expected population concentrations with their needs base on untraditional resources like solar and nuclear energy after conducting necessary studies on required precautions and finance
4. Making studies on groundwater and possibilities of seawater desalination to provide these extents with water needs

4.5 Policy 4.5: Resistance to the Disintegration of Land Tenure

Average of land tenure in Egypt is 1.26 ha [13]. This noneconomic part of land pushes its owners to sell it or tend to alternative activity. One of the reasons of land partitioning is the inheritance laws. When the owner of a land dies, the sons own the land as parts not as one unit. They may not be interested or involved in agriculture activities, and this finally leads to lose the productive value of the land. What is required here is creating regulations if the inheritors do not intend to keep the unity of land that does not conflict religious and law bases. This issue should be put forward for the community dialogue to reach the best acceptable mechanism.

4.6 Policy 4.6: Protecting Farmers Against the Expropriation of the Right to Use the Land

Sustainable agriculture incorporates the availability of the future use of resources. Agriculture should be viewed as long-term investment. Farmers should feel secure during their use of land. If they are not sure about how long they are permitted to farm in a piece of land, they will go far from resource-conserving technologies and modern practices. Any investments on such practices will be considered high risk for agricultural investors and donors in addition to farmers which will be reflected on the sustainability practices as a whole. Without protecting farmers' rights, any improvement in production may support the land owners to claim it from farmers and farm it themselves.

There is a need for a national program to coordinate the relationship between tenants and landlords to ensure the farmers' rights in benefits of improving the production through using resource-conserving technologies or any made investments by farmers. Landlords should be encouraged to set conditions that assure their benefits without prejudice to the rights of farmers to develop the land and to benefit from the return of their efforts.

4.7 Policy 4.7: Supportive Payments to Resource-Conserving Practices

Financial services are not accessible for many people whether on local or world level [14, 15]. Cost of sustainable agriculture practices is a real problem that faces farmers. There is a need for financial support program to encourage farmers to implement resource-conserving practices without being worried of the money required.

These grants can be paid back as a part of total production. Also this support should be introduced under conditions to insure the right application of practices. Extension and research organization are strongly needed to be involved to follow the practice implementation and keep continuous communication with farmers. Low-interest loans may be an acceptable solution for financing resource-conserving needs like machinery and equipment.

4.8 Policy 4.8: Monetary Incentives for Sustainable Agriculture Practices Adoption

Making monetary prizes for featured farmers who successfully implemented sustainable agriculture practices encourages them to be in continuous try not just keeping the practices but also developing it. These incentives create competitive environment between farmers to obtain the most possible beneficiaries of resource-conserving practices. Making monetary incentives keeps the farmer looking for improvement regardless of expected costs. Transparency and integrity are essential in this rewarding system with clear announced winning criteria. These incentives also should be high valued and multiple (not only for one farmer) to increase the feeling of winning possibility for all farmers.

4.9 Policy 4.9: Set Penalties with Taxes and Levies

If a system is required to reward good implementers of sustainable farming practices, punishment system should be created to punish those who insist to keep away from these practices. In sustainable agriculture community, resource-conservation practices are considered a must not a kind of welfare. All actors should work as one team and there is no choice for a person or a group to go far.

Environmental and public health costs are not accounted by farmers. These external costs should be paid by polluters. Imposing of taxes on external inputs such as chemicals leads to decrease their use. These supplements can be directed for the protection of natural resources like water resources and erodible lands. Establishing regulations will enforce farmers' compliance.

Applying this policy will reduce environmental impact of using chemicals and other pollutants like groundwater contamination. Also these taxes and levies should be in high level if there is a real intensity to protect agricultural environment and manage our natural resources in a sustainable way. Taxes and levies will work to protect groundwater and rivers. Low-level taxes can cause higher income for farmers, but it will have negative impact on the environment and the community as a whole. The proceeds of these fees can be directed to support the agricultural sector and sustainable agriculture research.

4.10 Policy 4.10: Marketing of Sustainable Agricultural Products

Most people can't distinguish between products according to its source or farming methods. Sustainable agricultural products are assumed to be more qualitative and healthy because of the adjusted amounts of inputs and minimized chemicals. Government can give support to sustainable agricultural products through media and advertisements to encourage people to turn out on buying these products after informing them about the difference between products.

The truth is these products may be more expensive than normal farming products. This can be solved by informing consumers about the healthy, environmental, and economic benefits of using such products. Government should also facilitate the procedures required from farmers to obtain brands for their products and support them for marketing. There is a need for information system to link producers with consumers and decision-makers to be aware of marketing policies and how can government involve small holders to be involved in marketing strategies as it is a common problem in most developing countries [16].

These steps will widen the application of sustainable agriculture practices as farmers will not be worried about marketing of their products. After this expansion it is expected that sustainable farming products will be equal in price to conventional products. In some cases government may direct farmers to mandatory production for some crops especially when it is related with strategic or exporting crops. Good payment should be introduced to the farmers in such cases if the production was sold to the government account. If not government should work on opening all marketing opportunities for farmers' products on local and international level to gain farmers' trust and assure their continuation in cultivating such important crops.

4.11 Policy 4.11: Accounting of Natural Resources

Current methods for calculating national income give misleading indicator about contribution of the agricultural sector. Some of the numbers are considered incomes but when following it we may find loses. The agricultural production is directly related to the consumption of natural resources. Even if the policy considered the depletion of natural resources is free, it does not change the truth that natural resource consumption is costive and should be taken into account. Environmental impacts of natural resource depletion will need finance to be cured. This means there should be a cash return for using these resources.

Adoption of natural resource account gives appropriate signal to the economic planners. Natural resource accounting should be included as essential part of any agricultural projects to give right indicators about required capital and opportunities of investments as it helps in planning for loan programs.

An example for the importance of this accounting is water. Water cost is essential part of designing irrigation systems as a part of capital costs [17]. In Egypt water is introduced as free resource to farmers despite the cost of water conveyance infrastructure and required maintenance. If the product was introduced in markets, the price of water will not be included in the product price. In this case the product may appear economic but after the right calculation we may find a loss.

5 Establishing Policy Framework for Agricultural Investments

General policies of sustainable agriculture should work in parallel with supportive policies for investments. Investments are required to cover the transition cost to sustainable agriculture practices. Developing countries prefer private investment in agriculture. Farmers are the main shape of investors as they do their efforts and take financing risk hoping to obtain returns. There are ten areas that should be considered when establishing the framework of investment policy [18].

1. Investment policy: Investment policy should be attractive to the investors. The investor should feel guaranteed and secured when being involved in investment process. This confidence reflects the quality of the policy. Transparency and nondiscrimination which will be reflected by secure access to land and water, well-functioning markets, and clear contracting mechanism will boost investor confidence.
2. Investment promotion and facilitation: Encouraging investment procedures should aim to cure market failure and make use of the available resources in the agricultural sector. Government should set a dialogue mechanism with investors and enable institutions or create investment promotion agency to share in both promotion and facilitation processes.

3. Infrastructure development: Besides the importance of infrastructure to apply the needs of the agricultural process such as irrigation networks, energy-providing networks, and transportation and communication tools, suitable infrastructure is one of the securities for investments.
4. Trade policy: Transparent, open, and oracular trade policies improve resource allocation. Government should announce a clear trend on trade agreements whether on the local or international level to give investors sufficient confidence about the returns of their investments.
5. Financial sector development: Generating economic activities is a direct responsibility to the financial markets. They have to provide finance for investors whether on small or large scale. The role of the government here is to set relaxing regulations to pay back the loans for an easy access to grants which will increase the activities and their expected return.
6. Human resources, research, and innovation: Skilled human resources attract and increase investment opportunities. Government should link the educational institution with extension services to provide training. Innovative research supported by protected intellectual property rights is required to meet the need of agricultural sector and support making investments in research. Research agreements with other countries may help to transfer a required knowledge for the agricultural sector.
7. Tax policies: Well-designed tax policy enables government and subnational authorities to increase revenue and attract investments.
8. Risk management: Agricultural sector is surrounded by many risks related to climate, diseases, price changes, etc. Good risk management policy will give investors the confidence in stable and predictable income.
9. Responsible business conduct: Investments should be sustainable by the meaning that it should not be harmful to the environment or society. Protecting laws and regulations are required to keep the aims of sustainable agriculture.
10. Environment: Clear laws and environmental policies can keep the required attraction for investments while protecting the natural resources against any negative impact for a non-responsible activity. Investors should be encouraged to adopt clean energy resources. Penalties should be set on the base of the extent of damage to the environment. There is also a need for clear announced environmental standards.

6 Monitoring and Evaluation of Policies

As mentioned before, there is a need for monitoring and evaluation system for the application of policies. Before evaluation, we must know that the success of any policy can't be perfect, and there will be a continuous need to improve the policy or replanning. Even on the local level, the degree of success can vary from a place or territory to another. Implementation of policies requires a prioritization process that has schedules of application on the short and long term.

Implementation process should be done with support from institutions and local groups to link all the actors and overlap implementation mechanisms. Monitoring and evaluation can be through specialized units that can work under the umbrella of MALR or one of its following institutions.

The suggested units will be responsible to do the following:

1. Following up the performance of project and practice implementation and making reports about their progress or current or expected obstacles.
2. Monitoring changes on the factors that affect the agricultural sector like climate, national and international marketing, other affecting policies from other sectors, etc. Of course they have to plan and suggest necessary actions to face the dangers.
3. Continuing improvement for the current policies.

Research institutes will play the most important role in providing decision-makers with required data and solutions for any problem that may prevent right implementation of policies. Studies about the opportunities of policies success and monitoring and evaluation mechanisms will be useful to improve the expected outputs of the strategies. Contacts and overlapping between all related ministers to agricultural sector will support the creation of successful sustainable agricultural system and the required policies.

7 Expected Impacts of Successful Policy Application

Beneficiaries expected from sustainable agriculture vary according to the type of the agricultural system.

Next points demonstrate the expected gain of applying sustainable agriculture:

- In industrialized systems, it is expected to obtain stabilized or lower yield with remarkable environmental improvement.
- The green revolution lands will obtain higher yields with little environmental beneficiaries.
- Significant increase in the agricultural yield coupled with more independence on external resources is expected in substantially increased agricultural yields in complex and diverse resource-conserving systems.

Egyptian agricultural system as complex and diverse system (refer to part 1) will give indices and evidences that it was impacted by sustainable agriculture practices when low or nonexistent use of external resources occurs.

Two- or threefold increase in crops production can be achieved by adoption of resource-conserving technologies on the community level [5]. This increase happened by including the low or nonuse of fertilizers and pesticides in farming programs based on soil and water conservation, IPM, green manuring, and land rehabilitation. Some case studies were achieved in some Third World countries which are classified as resource-conserving systems to evaluate the impacts of sustainable agriculture practices on crop yield production as the main expected profit in such systems.

Results indicated that all the resource-conserving practices caused an increase in yield varied between 90 and 600% [19–27]. In some cases different increase in crop production resulted in different countries with the same practice. This indicates the effect of the implementation method and surrounded environment on the benefits of the practice. According to these studies, it can be said that perfect success can't be achieved, but there are always opportunities for improvement or replan if needed. The key element of success may be the lessons learned from previous mistakes.

Sustainable agriculture can't be achieved without the support of well-planned policies. Policy application can't be separated from the sustainable system; it is an essential element to reach sustainability. Any benefits coming from sustainability is a gain for the supporting policies and its implementation. MALR expected obtaining beneficiaries from applying sustainable agriculture practices [9]. Expected gains are subject to shortfall, increase or non-achievement according to the quality of the practice application, and their follow-up according to guidelines drawn by policies. What is listed here is an expectation of some of what can be achieved for the agricultural system and rural community development through sustainability.

All the benefits will not continue forever by nature. There is always need for improvement and considerable policy flexibility to deal with changes or shocks that may affect the targeted sustainable system elements.

Sustainable use of natural resources: Impacts related to the sustainable use of natural resources include increase in water use efficiency, reclaimed land area, productivity of land and water units, and expected return. Current situation of agriculture resource use and expected improvement are listed in Table 1. The increase in land area will increase required water for irrigation. Modernization in irrigation systems is expected to cover more than the required amount besides the increase in water use efficiency. The return of water and land units will increase; this can be an essential reason to encourage farmers to keep improving their practices and feel assured about their investments.

Providing job opportunities in the agricultural sector: Development of the agricultural sector will provide direct and indirect job opportunities. Direct job opportunities are the jobs which are directly related to the field activities like farming and extension. Indirect job opportunities are the jobs related to the services introduced to agricultural sector like transportation. The great challenge here is the anticipated increase in population which normally may affect any national program for development. Indicators shown in Table 2 demonstrate that there is a prospective increase in agricultural working forces whether direct or indirect employing with ratios higher than the ratio of the increase in population. Sustainable agriculture practices will give desired attraction for investments in agriculture that will be reflected on the rural community development and welfare in addition to increased contribution in the national development.

Increased agricultural production: Data illustrated in Table 3 clarifies that there will be an increase in crop production per unit area. Increase in crop production is the main target of complex diverse agricultural systems like the one in Egypt. It does not mean to neglect the agriculture-based industry especially if we have good opportunities and sufficient experience to build or rebuild some of these industries. The increase in cotton production, in which Egypt has an international reputation

Table 1 Expected saving and development in land and water resources resulted from sustainable agriculture practices

Description	2017	2030
Quantities of water used in irrigation, 10^9 m^3	61	64
Field water use efficiency	75%	80%
Areas projected to be developed, 10^3 ha	945	2100
Total expected saved amounts of water, 10^6 m^3	5,300	12,400
Land areas expected to be added, 10^3 ha	525	1302
Average rate of return per water unit, L.E/m^3	3.2	4.17
Index of the increase in the returns of the water unit	168	218
Average rate of return of the land unit, L.E/ha	48,330	54,960
Index of the increase in the returns of the land unit	154	174

Table 2 Expected increase in agricultural working force compared to the increase in total population

	Estimated increase (in millions)	
Description	2017	2030
Total population	92	106
Rural population	53	62
Increase in the direct agricultural working force	0.4	1.0
Increase in the indirect agricultural working force	1.2	3.0
Total increase in the agricultural working force	1.6	4.0

Table 3 Anticipated increase in productivity of some crops, ton/ha

Crop	2017	2030
Wheat	7.68	8.64
Rice	10.8	12.48
Maize	10.56	12
Sugar cane	135.84	156.96
Sugar beet	67.2	84
Groundnut	4.8	6
Fava beans	3.84	4.32
Cotton	3.84	4.32
Citrus	28.8	36
Grapes	28.8	33.6
Olives	14.4	19.2
Mango	14.4	24
Tomatoes	48	72
Beans	16.8	19.2
Potatoes	28.8	33.6
Medicinal plants	2.64	3.12
Perennial clover	84	96
Dates (kg/tree)	110.0	120.0

about the crop quality, may create the opportunities to improve fiber industry sector. Egyptian strategic crops like wheat, rice, sugar crop, and maize yield production will increase which enhance the opportunities of increasing strategic reserve and self-reliance of such crops. Table 4 lists anticipated increase in livestock production. This increase will share in improving the nutritional standard of food for Egyptian populations, which are a main target for sustainable agriculture beside improving food quality.

Enhancing competitiveness of agricultural products in local and international markets: Improved product quality is in prospect result for sustainable agriculture practices. Policies may have a clear role here to increase product competitiveness.

Establishing and applying product quality standards will be easier by adopting sustainable agriculture practices. Supportive communication system, improving marketing services, and monitoring of marketing policies including risks are essential to assure success of linking products with market chains. Opening international markets to receive the Egyptian agricultural products by agreements and improved relationships with foreign countries are responsibilities mainly coupled to success of governmental policy application.

Raising self-sufficiency level in strategic food: Self-reliance is strategic aim for governments. This sufficiency especially in strategic crops has a lot of reflections on the economic and political situation of country on both local and international levels. Percentages, listed in Table 5 of expected self-sufficiency of crops by the year 2030, indicate that Egypt will have self-sufficiency of white meat, milk, and egg. But they may not have export opportunities. Citrus, grapes, potatoes, and tomatoes are crops that have good reputation in the international market because of their unique quality.

According to the indicators of their increase in production, they have a good opportunity for export and will need more efforts of marketing in foreign countries. Rice will reach self-sufficiency level, but it may need more improvements to reach a secure level of production to be exported. Wheat, maize, fava beans, sugar crops, red meat, and fish will need taking the necessary actions and considerations for both vertical and horizontal extent by creating and depending on highly productive species besides extending cultivated area of these productions.

Table 4 Livestock product increase

Product	2017	2030
Milk production, 10^6 tons	7.2	9.54
Milk imports, 10^6 tons	0.14	–
Red meat production, 10^6 tons	0.853	1.089
Red meat imports, 10^6 tons	0.251	0.077
Fattening broilers' production (million birds)	1095	1411
Egg production (billion eggs)	7.2	9.32
Sea fish production, 10^3 tons	200	250
River and lake fish production, 10^3 tons	295	320
Aquaculture production, 10^3 tons	1005	1390

Table 5 Rates of self-sufficiency of strategic food

Main food commodities	Self-sufficiency, %	Main food commodities	Self-sufficiency, %
Wheat	80.8	Citrus	176.9
Rice	103.1	Grape	165.1
Maize	91.9	Milk	100
Sugar crops	93.3	Red meat	93.4
Fava beans	90.6	White meat	100
Potatoes	184.9	Egg	100
Tomatoes	172.0	Fish	99.4

8 Conclusion and Recommendations

Sustainable agriculture needs supportive policies to its practices. Policies should be designed and planned in a participatory manner from all the community elements. Policy maker should be aware of the nature of sustainable agriculture.

Practices resulted from policies should be economically, environmentally, technically, and socially approved. Sustainable agricultural policies are built to serve the required integration between its elements by reforming and enabling external institutions, supporting local groups, and supporting resource-conserving practices.

Applying these policies needs the creation of national policy to ensure participation of all involved parties. Government should hold all the policies and monitor their implementation and make continuous evaluation for their impact to decide the need of making modifications or replanning.

This chapter indicated 22 policies that can be applied to support transition to sustainable agriculture and self-reliance. There are previous mistakes in policy making that led to give negative impact on the Egyptian agricultural sector.

All policies and suggested mechanisms should start from the farmer's needs. Keeping away from the farmers will lead to weaken extension system, related research, and policy applications. Farmers are participants in policy design, planning, and implementation. Because of their importance in the transition process, farmers' rights should be protected, and they should be financially supported to go through adopting the sustainable agriculture practices.

Policies can't be imported as the opportunities of success vary from place to another according to its local conditions. Policies should be supported by a pack of regulations and laws to assure the mandatory application of practices.

Expected beneficiaries show that going towards sustainable agriculture that is supported by policies and well-planned mechanisms for implementation is a required must to meet expected agricultural product needs on the national level.

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Update, Conclusions, and Recommendations for Sustainability of Agricultural Environment in Egypt: Soil–Water–Plant Nexus

Abdelazim M. Negm, El-Sayed E. Omran, and Mohamed Abu-hashim

Abstract By 2050, agricultural production has to increase by 7% to face the population increase. This production increase should be attained in a system that preserves the environment and limits the use of pesticides and undesirable chemicals in agriculture. This chapter encapsulates the key sustainability challenges (in terms of conclusions and recommendations) of the existing main agri-food system and presents insights derived from the cases in the volume. In addition, some (update) findings from a few recently published research work are related to the sustainability covered themes. This chapter focuses on the sustainability of the agricultural environment concerning Soil-Water-Plant Nexus in Egypt that was documented in this volume. To this end, we identify four main contribution areas, which include Egyptian sustainable agriculture, the potential application of natural products on crop productivity, biological control potentiality for sustainable agriculture, and livestock contribution to sustaining farm production. Therefore, conclusions will be built on researcher visions gained concerning study findings and limitations. In addition, this chapter contains information on a set of recommendations to direct future research toward sustainability of the agriculture, which is a main strategic theme of the Egyptian government. The set of recommendations is presented for professionals interested in pursuing additional research to exceed the scope and findings of this volume.

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Contents

1 Introduction

In recent years, Egypt has faced severe challenges due to mismanagement of natural resource, environmental degradation, and exponential increase in unattainable forms of consumption. Egypt is facing unprecedented resource crisis, particularly in energy, water, and food. Egypt has to rise agricultural production and succeed agricultural development due to the high rate of population growth, increasing demands for food, and the limited agricultural land resources. However, this production has to be attained in an environmentally friendly way that reduces the effects of greenhouse gases, the release of nitrogen and phosphorous, and the use of harmful pesticides. In this volume, audiences will learn more about how Egypt is shifting slowly toward sustainable agricultural practices.

Therefore, this chapter will present a general idea of the sustainable agriculture and its importance for Egypt and the researchers. In designing sustainable agricultural production systems, it is necessary to give due consideration to the characteristics of various resources used, soil–water–plant nexus, which renders the resultant production system unsustainable. So, the intention of the volume is to improve and address the following main themes:

- Integrated Natural Resources Management for Sustainable Production.
- Integrated Biopesticides and Biofertilizers for Sustainable Agriculture.
- Integrated Fish, Plant, and Animal for Sustainable Food Supply.

The next section will present a brief overview of the essential findings of some of the recent (updated) published studies on sustainable agriculture and then the main conclusions of the volume chapter in addition to the main recommendations for researchers and decision-makers. The update, conclusions, and recommendations presented in this chapter come from an investigation of data collection presented in this volume.

2 Update

Agriculture contributes about 13% of the Egyptian gross domestic product (GDP) and over 30% of employment opportunities. The Green Revolution technology led to doubling of food production between 1950 and 2010, with only a 10% increase in the area under production" [1]. However, meeting the food demand of the increasing population, rising standards of living, and changes in diet preferences will necessitate an additional 70% increase in production between 2010 and 2050 [2]. Agriculture production has to increase by 7% shortly to face the population increase. This production increase should be achieved through the sustainable agriculture system. The protection of human health, the environment, ecosystems, and biodiversity has recently been considered as an essential element in sustainable agricultural practices. Pest management has become one of the significant restricting factors for protected crop and vegetable cultivation in Egypt. Hence, it is vital that the agroecosystem and sustainable systems in agriculture be considered when deciding pest control methods. Yet, the application of synthetic pesticides is the main control method, which heavily contaminates the environment and affects the quality of produced crops and the safety of humans. According to FAO statistics in 2014 [3], Egypt used 2,274, 3,113, and 5,976 tons of pesticides, fungicides, and bactericides, respectively, a total of 11,363 tons.

The following are the major update for the volume project based on the main volume themes:

1. *Integrated Natural Resource Management for Sustainable Production*. Two approaches were identified to integrate natural resources to increase sustainable food supply in Egypt.

   The first approach identified to increase sustainable food supply is improving the salt-affected soil. Soil salinity has emerged as the most significant problem of present agriculture of Egypt. Egypt has about 160,000 ha in El-Tina plain of salt-affected soil, mostly saline or saline-sodic soil. Reclamation of sodic soils is a crucial worry at the global level. High soil salinity or "salt-affected soil" influencing, specifically, the arid and semiarid regions, contribute to the degradation of soil quality. Salt-affected soils and their management consequently constitute a real threat to global food security [4]. Saline and or saline-sodic soils are characterized by high salinity and high exchangeable Na^{+} and deficiency of Ca^{2+}. Various amendments have been used for reclamation of such soils. In Egypt, improving salt-affected soils is important for ensuring secure agricultural productivity.

   Plant tissue culture is the second way to face the food availability challenge in Egypt to cope with its fast-growing population in a restricted area of land. Conventional plant breeding is unlikely to meet increasing food demands and other environmental challenges. Modern agriculture exemplifies how research and technology can come together to improve crop yield and quality. Although conventional breeding was now much faster than it was 50 years ago, it is likely unable to keep up with the increasing demand for food and with the global environmental challenges that Egypt faces [5]. Plant tissue culture, as a modern biotechnology technique, is becoming nowadays very important for the development of humanity. It is considered one of the essential breeding methodologies for many crops, vegetables, and fruits, and it offers a substitute method for conventional vegetative propagation.

2. *Integrated Biopesticides and Biofertilizers for Sustainable Agriculture*. Five potential approaches were identified for using biopesticides and biofertilizers as natural products to increase sustainable agriculture in Egypt.

   The first approach is to use organic fertilizers to help in solving the problem of shortage in food production to face the demand of the fast-growing population in Egypt using bio-augmented N-enriched organic fertilizer. Increasing the productivity of crops, such as oil crops and cereals especially sunflower, wheat, and barley, became a necessity to minimize the gap between our total production and consumption. Currently, there is a gap of more than 10 million tons of plant nutrients between consumption through cultivated crops and chemical fertilizers added. Artificial fertilizers can cause the emission of greenhouse gases, which threaten the environment with its detrimental impacts. These impacts incorporate the degradation of soil fertility, water hardness, the increment in the dangerous residue, and advancement of resistance in insects. Concerning both the financial cost and the environmental impacts of chemical fertilizers, excessively high use of excess chemicals cannot be sustained in future periods due to the high cost. To overcome these challenges, organic farming is the new trend that includes the use of sustainable farming practices like the use of biofertilizers [6]. In this specific circumstance, organic and biofertilizers would be the suitable alternative for farmers to build profitability per unit area. Organic agriculture is the framework that supports the extreme utilization of organic matter and microbial fertilizers to enhance soil health and increase yield. Organic agriculture has a long history, but it shows a recent and rapid rise. For sustainable agriculture, there must be a positive link between the nutrients applied to the soil and crop uptake. This link could be more firm and sustainable if we employ an integrated approach, i.e., the use of bio-augmented N-enriched organic fertilizer. In this way, we would be employing a sustainable approach to meet the needs of crops for N in an environment-friendly way.

   The second potential way is to use plant growth enhancer. The dependency of the farmers on the use of inorganic fertilizers as a source of plant nutrients imposes high cost and leads to degradation of soil and environment [7]. One of the most critical constraints to agricultural production in the world is abiotic stress conditions prevailing in the environment. Soil salinity is a standout among the most brutal environmental factors restricting the productivity of plants. The issue of soil salinization is a scourge for agricultural productivity worldwide. Crops developed on saline soils suffer from an account of high osmotic stress, nutritional disorders and toxicity, poor soil physical conditions, and reduced crop productivity. Reclamation of salt-affected soil requires an improvement of physical, chemical, and biological properties. Soil humic substances such as humic acid and fulvic acid are mainly derived from the (bio)chemical degradation of plant and animal residues and from microbial synthetic activity, and they constitute a significant fraction of the soil organic matter. Thus, there is a need to search continuously for alternatives, which are safe, a natural source of plant nutrients, and growth enhancers and even ward off pest and diseases. One such alternative is *Moringa*; *Moringa oleifera* is one of such option being explored to discover its effect on growth and yield of crops and, therefore, can be encouraged among farmers as an ideal plant growth enhancer.

Pesticides are used uncontrollably by the producers who ignore their consequences, which created serious health and ecological problems. Scientists around the world and in Egypt are investigating numerous alternative approaches including plant natural extracts, specific secondary metabolites, intercropping crops (allelopathic and/or defense inductive effects), and nanoformulations of secondary metabolites and/or pesticides. Several natural products, materials, and tactics were used as acaricidal/miticidal alternatives. Biocide plants are imperative sources of regular substances that could be utilized as choices. In the 26 plants screened for antifeedant activity, three plants indicated important antifeedant activity, viz., *Pseudocalymma alliaceum*, *Solanum pseudocapsicum*, and *Barleria buxifolia* in ethyl acetate extracts against *Spodoptera litura* and *Helicoverpa armigera*, respectively [8]. Plant chemicals from *Pseudocalymma alliaceum*, *Solanum pseudocapsicum*, and *Barleria buxifolia* by the green chemistry approach have been utilized to control economically important pests alternate to synthetic pesticides. Plant extracts and essential oils (EOs) were effective in controlling the acari with varying degrees of potency compared to synthetic acaricides. Neem oil (*Azadirachta indica*) currently remains the only product used as a biopesticide by most producers [9]. Thyme oil prompts resistance against *B. cinerea* through the preparation of protection responses in apple fruit, and the PR-8 gene of apple may play a key role in the mechanism by which thyme essential oil effectively inhibits gray mold in apple fruit (Banani et al. [10]). Another approach was the application of salts and inorganic acids, e.g., boric acid, ascorbic acid, and potassium sorbate, as pesticides alternatives against the *Polyphagotarsonemus latus* (Banks) mite and *Myzus persicae* (Koch) aphid on potato plants. The results were similar to that of the Ortus acaricide [11]. Examples of the bio-control products that commercialized in Egypt are Bio-fly (*Beauveria bassiana*) against white fly and Bio-Zeid (*Trichoderma album*), Rhizo-in (*Bacillus subtilis*), and Bio-Arc (*Bacillus megaterium*) against fungal diseases. Mass production of insect predators is still in progress and needs higher technology in production and storage. It can be concluded that Egypt has the potential to promote its biological control and contribute more to sustainable agriculture.

Climate and weather can significantly affect the development and distribution of insects. Current estimates of climate changes are estimated to rise in annual global mean temperatures of 1°C by 2025 and 3°C in the next century. Climate change resulting from the continuous emission of anthropogenic emissions of greenhouse gases affects the natural and human systems and sectors throughout the world, and changes so far may only be profound changes in the future. Climatic change plays a vital role in the agriculture crop production and the pests and natural enemies associated. The relative growth rates of crops and insect phytophages are likely to differ between temperature regimes. We ought to hence expect insect pest pressure at a location to change with climate warming [12]. More than 10,000 species of insects, 600 weeds, and 1,500 fungi, as a typical pest name, adversely affect daily human life. They reduce the quality and quantity of food produced by reducing production and destroying stored products, compete with humans for food, and cause many diseases for humans, animals, and crops. Humans began to control pests at the same time they started farming. Climate changes were effective integrated pest management such as cultural practices like crop rotation, early/late planting, pesticides, and natural enemies. It is worth mentioning that in 2017, the MALR [13] issued the certified control recommendations of agricultural pests in Egypt to be used as a guide to control the pests in step to improve the agriculture productivity.

Insect growth-inhibiting proteins are a biological control for sustainable agriculture. The combination of various pest management strategies is required for the advancement and implementation of sustainable IPM programs. This can be accomplished by utilizing cultural methods in harmony with other alternatives to pesticides. Also, using biopesticides and host plant resistance have always been key elements in transgenic techniques and IPM programs for agroecosystem. Also, biological control is also an important part of the agroecosystem. Behavior-modifying chemicals, as well as non-behavior-modifying pesticides, have also played important roles in IPM. Several new trends were used in pest control such as biotin-binding proteins (Avidin and Streptavidin). Avidin and streptavidin are insect growth-inhibiting proteins whose genes could potentially be expressed in tobacco plants expressing avidin; streptavidin provide inbuilt plant resistance to larvae of *Spodoptera litura* and *Phthorimaea operculella*. The toxic effect of these proteins toward insect pests was established by growth retardation leading to effective mortality of these larvae out [14]. In addition, chitinase enzymes produced by different microbial, plant and insect species catalyze the hydrolysis of chitin [15]. Chitinase enzymes target chitin in the peritrophic membrane of the midgut causing a reduction in survival and growth out.

3. *Integrated Fish, Plant, and Animal for Sustainable Food Supply*. Four approaches were identified for integrated fish, plant, and animal as a potential way for sustainable food supply.

The first approach is integrated agricultural systems. Agriculture has been extremely fruitful in tending to the food and fiber needs of the present world population. Nonetheless, there are expanding worries about the economic, environmental, and social costs of this achievement. Integrated agricultural systems address these worries while expanding sustainability. Dynamic-integrated agricultural systems have multiple enterprises managed in a dynamic manner [16]. The integration between crop production and the spread of animal production farms is vital to increase sustainable food production. Livestock is an essential pillar of the national economy in any country and a key element in achieving its food security. The livestock development is a key goal to cover the current shortage of animal products due to increased demand. The main reasons for the decline in livestock productivity are limited feed resources, high prices, and inability to cover food needs. Therefore, mixtures explore the available environmental resources and increase yield per unit area and give a balanced diet for feeding animals.

The second approach is the integrated aquaculture–agriculture systems. The interventions in an integrated farming system mode covering crop-livestock–aquaculture were planned and demonstrated, considering the overall need of the area, available technological options, market accessibility for both input and produce, etc. [17]. The establishment of fisheries in desert areas and recycling the wastewater of those fisheries to cultivate plants, which represent chain aquaculture seems to be the most plausible solution for problems such as pollution and limited water resources. Algae play multiple beneficial and cost-effective roles in that system. Concomitantly, algae play a central role in integrated chain aquaculture by starting the chain through adding algae to fish feed as well as in biofertilization and soil stabilization. Today, the stress is on incorporating the utilization of the kind of feed where the fundamental objective is to limit nutrient loads in the surrounding natural ecosystems and to maximize the usage of the unit's water resources. Different present integrated freshwater aquaculture frameworks, such as intensive fish production joined with wetland, recirculation aquaculture system, and multifunctional aquaculture, have demonstrated their feasibility [16]. Overall, the integrated aquaculture–agriculture system offers solutions to pollution, limited resources, and water scarcity through using and recycling natural resources.

Over the past years, developing genotypes of poultry are mainly driven objecting the best productivity performance at optimal environmental conditions since recent elevation in extreme heat wave events and increased sensitivity of the modern genotypes of poultry to heat burden became an essential concern [18]. Heat stress is a standout among the most critical physiological factors challenging poultry production all over the world mainly in tropical and subtropical countries. Oxidative stress induced by heat stress not only compromises productivity and performance but also results in morbidity and mortality losses leading to the economic burden for poultry producers. It lessens the shelf life of poultry product in addition to poor meat and egg quality [19]. Recently, a pattern toward utilizing phytochemicals obtained from normal sources with potential antioxidant activities has increased.

In recent decades, foods are expected to fulfill hunger and supply the necessary nutrients for consumers, as well as to reduce or prevent nutritional diseases and enhance the mental and physical well-being of humans [20]. The production of organic poultry has increased in several countries, but it is still relatively small. This positive trend is as a result of increased preferences of consumers for organic poultry products (meat and eggs) that are perceived to be secure under the production system. These products reduce the use of drugs, antibiotics, synthetic fertilizers, genetically modified crops, pesticides, and hormones which lead to many adverse effects on consumer health. It is interesting to note that organic products are often the trigger in moving toward a healthy lifestyle, which then ends up also involving other sectors and products looked for on the market [21].

The guidelines for this system were expanded in an attempt to study and use an alternative to traditional production.

3 Conclusions

Throughout the current volume, the editors were able to reach several conclusions, which have been drawn from this volume. Besides methodological insights, the chapter originates key lessons from the cases in the volume, in particular, the promising characteristics of both the historical and current local food system. These conclusions are essential to increasing sustainable food supply in Egypt. These are discussed in the following in no particular order.

- *Integrated Natural Resource Management for Sustainable Production*

  There are several theoretical and experiential equations around the world to estimate ETo. The choice of any one technique depends on the accuracy of the equation under a given condition and the availability of the required data. Nassar et al. [22] set the proper land, water, and crop management under saline irrigation practices with a good yield without any deterioration in soil productivity. Ghandour [23] used the Simulation of Evapotranspiration of Applied Water (SIMETAW) model to decide actual rainfall and evapotranspiration of applied water (ETaw) for crop and land-use categories, which include similar crops by different regions, having similar ETo rates within California and Egypt Delta. The SIMETAW model simulations provide a method for determining ETo and ETc using minimum weather data set under Nile Delta conditions. The model estimates ETo from generated daily weather data using the standardized reference evapotranspiration (modified). SIMETAW demonstrates high accuracy in simulating the initial weather parameters in the Nile Delta needed for calculating ETo and simulating ETo and ETc for a long time series. This information is vital to develop plans for water supply and distribution across the Nile Delta. For more information, see chapter "Land, Air, and Water Resources on Sustainable Agricultural Development in Egypt."

  Soil salinity in agriculture soil refers to the occurrence of high concentration of soluble salts in the soil moisture of the root zone. These concentrations of soluble salts through their high osmotic pressure affect plant growth by limiting the uptake of water by the roots. Salinity can also affect plant growth because the high concentration of salt in the soil solution interferes with balanced absorption of necessary nutritional ions by plants [24]. The well-known practical way to reduce excessive soluble salt in soils is to leach the salt out by the passage of low-salinity water through the active root zone depth of the soil. Several theories had been developed to predict the need to leach, but various required parameters limit their usefulness without on-site calibration [25, 26]. The obtained data showed intermittent leaching 0.4PV (L3) was more effective in decreasing EC, soluble ions, ESP, and exchangeable magnesium and increasing exchangeable calcium as well as improving physical properties (i.e., water stable aggregates and hydraulic conductivity) than the other one (i.e., intermittent leaching 0.1PV or 0.2PV). There was a decrease in pH, EC, and ESP values for the degraded soil reclaimed using all amendments. Infiltration rate of water increased due to amendments through enhancement of soil aggregation. Also, the thorough mixing application showed superiority over the surface application of gypsum, whether normal gypsum "NG" or phosphogypsum "PG" was used. All amendments proved greater efficiency compared to the control treatment.

Plant tissue culture has proven to be a thriving industry allowing the increased production of essential crop plants and has thus contributed to the Second Green Revolution. Increased rate of crop production, as well as improved crop varieties, will be facilitated with plant tissue culture techniques. Improving and investing in plant tissue culture will thus likely have a significant effect in agriculture sustainability and in creating several employment opportunities in the field of agriculture industry. Tissue culture propagation had also been very successful in producing improved self-sufficient crops widely used in developing countries [27]. The study recommended supporting and improving banana production by tissue culture, as a replacement for traditional production to raise the crop productivity and exports of Egyptian banana [28]. Date palm is also a major agricultural crop that has excellent nutritional value and health benefits. It is propagated either sexually by seed or vegetatively by offshoots. Seed propagation has some limitations such as high percentage of male plants and slow growth [29].

- *Integrated Biopesticides and Biofertilizers for Sustainable Agriculture*

  Climate change is expected to have a negative or positive effect on the short- and long-term diversity of pest's abundance, pest's-host plant interactions, an abundance of natural enemies. Finally, it is expected to have an effect on the Egyptian economy due to the impact on agricultural economic crops. Grain yields of wheat [30] and rice [31] are sensitive to high temperatures [32]. The significant change in climate is reflected in the increase in the average temperature of the globe and the change in precipitation amounts, their patterns, and their locations. These seasonal and long-term changes will affect the crop production and enabled the emergence of new plant species that were not previously known. In other words, any change in the components of the environment will be reflected in human lifestyles and the pests associated with their crops. The rapid climate change also influences the insect evolution and makes its adaptation to climate change an indispensable thing as their migration largely depends on abiotic factors such as temperature, relative humidity, and wind direction. A slight change in these parameters will alter their migration pattern largely.

  The basic principles of IPM are scouting and thresholds, which reduce the use of pesticides by 50%. Integrated pest management is carried out in a sustainable manner by a combination of "biological, cultural, mechanical, physical and chemical tools in a way that minimizes economic, health and environmental risks" (<https://www.epa.gov/sites/production/files/2016-02/documents/2016-2017_school_ip>). Despite the importance of the biological control in IPM, the basic principles of IPM are scouting and thresholds. If scouting and thresholds were the only IPM methods practiced by a grower, pesticide use could usually be reduced by 50% compared to spray on a regular schedule. Advantages of the use of pest-resistant varieties include low cost, increased security to the grower, decreased use of insecticides, the potential to enhance biological control through conservation of natural enemies, easy transferability to farmers' fields, no danger to humans and domestic animals, and compatibility with all other control practices. Several new classes of insecticides became available and been registered in various crops. These compounds are highly efficient and very selective.

The application of pesticides would save the plants' yield (quantity and quality) but would put a huge burden on the environment, human health, and wildlife. Therefore, finding alternatives and/or synergistic agents of pesticides has been the major task of thousands of scientists all over the world. The application of natural origin with and/or without the nano-sized preparations would offer crop protection programs with the following advantages (a) have different materials that are active under various environmental conditions, reach the noxious pathogens, (b) kill the pest effectively, safe to plants and mammals, (c) cost-effective to manufacture, (d) have varying mode of action, and (e) provide economic returns and social benefits. However, increasing attention must be devoted to the impact of risk factors associated with their use of the environment and possible adverse effects on nontarget organisms and mammals. Nanoparticle formulation of pesticides, natural chemicals, and/or microorganisms or their cell constituents has demonstrated greater efficiency than commercial counterparts. Research in the polymer-based formulation (nanoemulsion, nanoencapsulation, etc.) is rising, while research on the application of classical nanoparticles (nano-metallic) is slowing down for plant protection purposes. Nano-polymerization models might be promising for the delivery of the active ingredient to the target and are thus expected to receive the most attention in the future. Moreover, the lack of knowledge on the efficacy of nano-pesticides in field trials would encourage more field experiments. The development of nano-pesticides ought to be very beneficial in a way to attract the attention of pest management enterprises in order to revolutionize this industry. Numerous alternative approaches including plant natural extracts, specific secondary metabolites, intercropping crops, and nanoformulations of secondary metabolites and/or pesticides are existing [33]. These alternatives showed promising potentials as anti-pathogenic agents. For more information, see chapter "Pesticides Alternatives Use in Egypt: The Concept and Potential."

Sustainable agriculture is a system for maintaining production in the end without degrading the natural resources by using low-input technologies. These technologies should improve soil fertility, enhance biological pest control, maximize recycling, etc. [34]. Sustainable agriculture has been ignored and suffered from limited adoption [35]. Integrated pest management programs avoid using chemical pesticides except in case of necessity using selective pesticides at optimal concentrations and time to protect the natural enemy population in Egyptian fields [36]. Of the most fruitful examples of biological control, the use of the egg parasitoid *Trichogramma* to control the sugar cane borer *Chilo agamemnon* in sugarcane in Upper Egypt. The same parasitoid species was released to manage the bollworms in cotton fields in Delta governorates. The predatory mite *Amblyseius swirskii* and *Phytoseiulus persimilis* was also used successfully in controlling the two spotted mite on vegetables in greenhouses of the investment companies.

Application of biofertilizers and compost (organic farming) is essential due to their effect on improving soil physical, chemical, and biological properties, besides compost represents a storehouse for all essential macro- and micronutrients. The organic product would help the farmers in reducing their expenditures to purchase chemical fertilizers and would reduce the import budget on a national level. Applied organic manure led to improving barley grain quality. Improve biology course in the farm, especially nutrient course, to produce healthy food of high quality and in sufficient quantity [37]. It does not only sustain higher levels of productivity but also improves soil health and enhances nutrient use efficiency [38]. Biofertilization is of great importance in alleviating environmental pollution [39, 40]. Also, from the economical point of view, the use of organic manure decreases the needed amounts of chemical fertilizers and produces higher yield and better quality of barley grains with a relatively lower cost. Finally, under the current experimental conditions, applied compost manure at the rate of 6 Mg ha^{-1} in combination with urea at the rate of 179 kg N ha^{-1} is essential to achieve the highest growth parameters of barley plants under salinity and sodicity stresses.

The adverse effect of salinity (major abiotic stress) on plants may lead to disturbances in plant metabolism, which consequently leads to a reduction of the plant growth and productivity. An increase in soil salinity commonly results in a reduction of water intake of plants. Passive nutrient uptake of the plants is related to water intake, and any decrease in water availability causes to a reduction in uptake of many plant nutrients [41]. There is increasing interest in the potential use of humic substances as plant growth promoter. Application of humic acid at a rate of 1,000 mg kg^{-1} to saline soil gave an increase in seed germination, plant growth, and macro- and micro-nutrient contents of tomato [42]. Humic materials could enhance the growth of the plant under soil condition with improving nutrient uptake and diminishing toxic element uptake [43, 44]. Their applications also give numerous advantages to agricultural soil, including amplified ability to retain moisture, a better nutrient-holding capacity, an improved soil structure, and a higher level of microbial activity. Humic acids can significantly diminish water evaporation and increase its use by plants in non-clay, arid, and sandy soil. Also, humic substances support the alteration of a number of mineral elements into forms available to plants. Application of humus materials as humic or/and fulvic acids under salt stress had a beneficial effect on plant growth, nutrient uptake, and available nutrients. Addition of Humic Acids (HA) combined with Foliar Spray (FA) with Moringa Leaf Extract (MLE) gave the highest values of plant growth, fresh and dry weight, NPK uptake of sudan grass, and available N, P, and K under different soil salinity. Foliar spray of MLE gave an increase of all parameters, i.e., growth, yield, and nutrient content in sudan grass, compared to untreated plants under soil salinity. Photosynthetic pigments, nutrient uptake, and available N, P, and K significantly decreased within each humic substance application and MLE with increasing salinity concentration. The highest values of fresh, dry weight, photosynthetic pigments, and NPK uptake under different salinity levels were observed with application of humic substances and MLE. The treatment of HA and FA with or without spraying MLE gave the highest values of available NPK under the salinity levels. For more information, see chapter “Using of Humic Substances and Foliar Spray with Moringa Leaf Extract to Alleviate Salinity Stress on Sudan Grass (*Sorghum vulgare*).”

- *Integrated Fish, Plant, and Animal for Sustainable Food Supply*

  The integrated aquaculture/agriculture approach seems to overcome several obstacles and challenges in conventional agriculture. Integrated aquaculture–agriculture would offer natural fertilizers derived from the wastewater recycled from fish culture [45] including phosphorus, nitrogen, and organic matter [46]. Applying a balanced, wise, and sound agricultural policy that takes into account the importance of economizing water usage combined with achieving successful integration between fish culture and agriculture would allow sustainable development. The fish wastewater is to be used for irrigation of plants thereby acting as natural fertilizers as waste from fish is rich in P and N, which are essential plant nutrients, thus replacing the harmful chemical fertilizers needed for plant growth. Algae serve multiple purposes such as fish feed [47], biofertlizers, and soil conditioners [48]. They will not only serve as biofertilizer and fish feed but also would work as soil conditioner/enhancer.

  Despite the great importance of Egyptian clover as the first green forage crop in Egypt, the low rate of fiber, especially in the first cutting, leads to digestive disorders in animals. Grass-clover mixture contributes to increasing of fiber. The most important of these forage mixtures was Sudan grass-cowpea, fodder maize-cowpea, fodder maize-guar, ryegrass-clover, barley-clover, and canary grass-clover, which succeed under Egyptian conditions. Forage mixtures increase their productivity compared with the pure stand of each component [49, 50]. For more information, see chapter “Importance of Forage Mixtures in Increasing Sustainable Food Supply in Egypt.”

  There has been increasing demands for organic food, which are expected to continue to increase in the near future, due to their ability to reduce the risks of many diseases and enhance the physical and mental well-being of the consumer, besides satisfying hunger and supplying substantial nutrients. Organic foods of animal origin are produced by feeding the animal on a specific diet or by using some techniques, like induced genetic mutation, genetic engineering, cross-breeding, etc., with an aim to guarantee the presence of nutrients, which may be useful to human health. To produce organic/designer food, it is essential to study the availability and sustainable nutritional strategies and evaluate knowledge-based alternatives of growth enhancers as well as develop more efficient models and protocols for quantification of the bioavailability and bio-accessibility of bioactive compounds for health studies in animal and human. Organic eggs, viz., specialty eggs and vegetarian, immune-powered, functional and designer eggs, do have increased content of vitamins, minerals, and essential pigments like carotenoids, lowered cholesterol and fat, balanced ratio of omega-6 to omega-3 fatty acids, antibacterial active principles, and an additional boost of antibodies. However, organic meat contained a higher concentration of tocopherol and conjugated linoleic acid, omega-3 fatty acids, protein, and amino acids; all these factors contribute to the maintenance and the improvement of consumer health. Interestingly, canola oil as an organic feed is used to change the ratio between saturated (SAFA) and poly-unsaturated fatty acids (PUFA). Healthy egg offers a balanced ratio of PUFA:SAFA (1:1) or omega-6 to omega-3 PUFA (1:1). Omega-3 PUFA are essential compounds which improve the development of the brain and immune functions, causes a reduction in blood pressure, and lowers platelet aggregation and atherosclerosis incidence. It is protective against some kinds of cancer and Cardiovascular disease (CVD) [51].

Poultry diet is a significant component of an overall lifestyle that can have a significant effect on human health. Livestock systems range from farms of cattle and sheep in the grassland areas to mix livestock systems including sheep, cattle, goat, swine, and poultry of a range of strains and breeds and of different sizes of the flock. Due to this variation, nutritional strategies that aim to obtain 100% organic feed through the given time scale need to be tightly related to the farm position and cannot be based on blueprint recommendations. The analysis of homegrown feed ingredients and accurate calculations of diet nutrients according to the nutritional requirements of the different phases of age is essential to improve the efficiency of diets. The use of genetically modified food is one of the most promising biotechnological applications. Organic or functional food produced by genetic manipulations will have a significant role in animal and poultry production, agriculture, medicinal aspects, and society as well. Organic food of poultry origin may only include organic eggs and organic chickens.

With increasing global temperature and lowering heat tolerance of the modern genotypes of poultry, heat stress has emerged as a major concern causing many economic losses to poultry production. Heat stress causes harmful influences on growth performance, carcass traits, meat quality, egg production, and egg quality and reproduction. High environmental temperature leads to a wide range of deleterious impacts on physiological and performance traits in poultry [52, 53]. To date, many published studies in heat stress in poultry focused mainly on exploring strategies to interfere with the conditions, which cause heat burden. These conditions include nutritional supplementation and environmental management although the effectiveness of these conditions varies due to breed, sex, age, geographical location, and management. There is a scope for exploring innovative approaches, involving the application of molecular techniques in poultry breeding to enhance poultry productivity in a sustainable manner as well as a genetic marker-assisted selection of poultry breeds for high heat tolerance. Subsequently, keeping in view the current situation, it is vital to well understand the different molecular and cellular mechanisms included in poultry production. These mechanisms are like immunological and physiological aspects of poultry birds exposed to heat stress.

4 Recommendations

A key aspect of sustainability is the ability to adapt to future challenges. We argue that sustainable systems need built-in flexibility to achieve this goal. Throughout this volume, the editorial' teams noted some areas that could be explored to further improvement. Based on the authors' chapters, the following set of recommendations could be stated for future researchers in exceeding the scope of this volume.

- Use forage mixtures (cereal grass and legume crops) as one of the farming methods to increase productivity and quality of forage and overcome the shortage in production of forage crops that maximize utilization of available environmental resources and increasing output of forage mixture.
- The future application of integrated aquaculture/agriculture approach will help in the following: (a) the maximum use of underground brackish water for various purposes such as growing algae, fish, and plants and recycling of wastewater, (b) the expansion in inland aquaculture and testing the different aquatic animals for growth and proliferation in hot desert areas, and (c) the use of algae for improving soil conditions and as biofertilizers solely or in combination with other microorganisms such as mycorrhiza.
- The SIMETAW model could tremendously help Egyptian irrigation engineers with limited research funding to improve their knowledge of crop water requirements and to address limited water supplies. However, more calibration is required for SIMETAW model to assess the effect of interannual climate variability (particularly, both precipitation and wind speed) on the model simulation accuracy. More calibration is needed to address the effect of the water stress conditions and local management procedures in the accuracy of the SIMETAW simulation. Since the SIMETAW was calibrated only in the Nile Delta, calibration for the other regions is recommended.
- Application of chemical amendments enhanced reclamation and caused more decreases in salinity as well as sodicity, and generally, intermittent leaching was more efficient in decreasing EC, soluble ions, ESP, and exchangeable magnesium and increasing exchangeable calcium as well as improving physical properties (i.e., water stable aggregates and hydraulic conductivity) than continuous. Leaching using amendments led to the improvement of the chemical and physical properties of saline-sodic soil.
- In the future, new culture-independent methods like LMW RNA profiling and PCR based on nucleic acid composition are required to study the function and ecology of microbes involved in nutrient cycling in soil. The techniques mentioned have been found not only independent of culture media composition or growth phase of microorganisms but also are precise and reproducible. These techniques also made it possible to utilize different biotechnological tools like an amplification of targeted genes or to quantify their expression. Overall, these techniques have opened new horizons in order to solve out the puzzle related to organic fertilizers and to assess which type of inoculants is preferable under different environmental conditions. The expansion of organic agriculture will be

a benefit in some areas of the project of reclamation of 1 million and a half million acres, in addition to the state's interest in the expansion of agricultural plantations. Also, Egyptian organic agriculture has a comparative advantage in terms of production dates and quality of European market countries.

- Future research is needed, particularly on field evaluation and application of humus substances, i.e., humic and fluvic acids and foliar spray with moringa leaf extract as biofertilizers in the stressed soil. More studies are needed on different crops mainly field crops semi-tolerant to salinity and drought. Physiological studies are fundamental to clarify the specific effects of its component. More research may be needed to clarify the mechanisms of alleviation done by fulvic and humic acids and their salts.
- Future research in the field of plant tissue culture should focus on the production and propagation of genetically homogenous disease-free plants and especially the essential economic crops to meet the continuously increasing world demand. Somaclonal variation is considered an important source of genetic variability that should be exploited to obtain new stable genotypes that can be grown in different types of soil. In vitro culture of zygotic embryos should be used to recover plants obtained from intergeneric crosses that do not yield fertile seeds. Plant tissue culture is an indispensable tool for genetic engineering in plants to grow plants that are tolerant to both biotic and abiotic stress factors. Decision and policy makers are highly encouraged to invest in new plant tissue culture techniques that suit the agriculture of different crop varieties and in different parts of the land.
- More research is needed on the risk associated with the applicability of natural extracts and specific mode of action of these materials to phytopathogenic pests and nontarget organisms. Incorporation of plant metabolomics, proteomics, and genomics in the study of botanical products and nanomaterials might speed up this work exponentially. More importantly, the collaboration between biology, chemistry, and pest management researchers is necessary for standardization and maximization of extraction, purification, derivatization, and synthesis of such biologically active components and in studying their toxic effects for humans and beneficial organisms. The majority of findings of the potential use of botanical pesticides and nanotechnology in agriculture are still at the experimental level, and very limited steps were pursued toward production or development of commercial products. Several factors hinder such advancement either in Egypt or worldwide including lack of (a) real links between industry and researchers or research institutions, (b) adequate investments for researchers to prepare their products commercially, (c) directed-companies, (d) components that safe to the environment, (e) effective natural components as pesticides, (f) Governmental regulations on the use of natural products, and (g) nanoparticles in pest control programs.
- There is a growing awareness toward the hazards of agricultural chemicals and the need for the biological control for conserving the environment and realizing the sustainable agriculture in Egypt. What is still needed to support the decision maker in the country is the infrastructure and some equipment. Egypt has a large market of biological products represented mainly by the agricultural investment

companies, which export these organic products of vegetables and fruit to Arab and European countries. With giving more support to the biological control infrastructure, mass production, and field application technology, Egypt would have a cleaner environment with a more stable system of sustainable agriculture. Therefore, biological control should be the main part of sustainable agriculture in Egypt in the nearest future.

- We recommend that all farmers and exporters especially in Egypt carry out integrated pest control programs in the management of crops, vegetables, and fruits to reduce the economic cost and to minimize environmental and health risks. Also, the following recommendations for future considerations are highlighted. Study the impact of climate change on insect population dynamics, migration and their natural enemies. The need to breed crop varieties that are more resistant to heat stress and insect pests. Adjust sowing dates to prevent insect pest's outbreak. Support and advise farmers on how to use integrated pest management more efficiently.
- Several points should be considered to mitigate heat stress in poultry farms like ensuring that outdoor air can smoothly flow into and out of the poultry house, practicing feeding at cooler times of the day, removing feed 4–6 h before an expected heat stress period, and dimming light during feeding. Furthermore, using good ventilation design, improving the energy level in poultry diets, and enriching the diets and drinking water with minerals, vitamins, antioxidants, and probiotics are also recommended.
- Technologies like monitoring insect pest migration with GIS, forecasting pest outbreaks, and modeling will help us to cope up with the changes in insect migration aggravated due to climate change. The insect migration in the pretext of climate change will result in the arrival of a new insect pest in a new geographical region or earlier onset of existing insect incidence in a country. Thus, the insect migration needs to be studied extensively in the changing climate scenario. For more information, see chapter "Impacts of Climate Change on Insect Pests of Main Crops in Egypt."
- To produce organic/healthy products, it is essential to study the availability and sustainable nutritional strategies and evaluate knowledge-based alternatives of growth enhancers as well as develop more effective models and protocols for quantification of the bioavailability and bio-accessibility of bioactive compounds for health studies in animal and human. Despite these promising features, consumers cannot readily accept the recent changes especially those of transgenic nature. So, the health benefits of organic poultry products (eggs and meat) should be investigated well based on accurate scientific studies. The development of poultry production and industry is not only depending on producing a large number of eggs and a significant amount of meat but also on producing more healthy foods.

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