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Series Editors: Damià Barceló · Andrey G. Kostianoy

Abdelazim M. Negm
Mohamed Abu-hashim *Editors*

Sustainability of Agricultural Environment in Egypt: Part I

Soil-Water-Food 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; geo-ecology; 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 six parts comprising 16 chapters written by more than 20 researchers and scientists from Egyptian university and associated research centers.

The production of the two volumes titled *Sustainable Agriculture Environment in Egypt* is essential to answer many questions connected to water, agriculture, land productivities, food security, sustainability of agriculture in Egypt and its applicability, and others. This is because the agricultural sector is considered the main consumer as it is one essential core of the Egyptian economy and the agricultural sector approximately consumed 59 km^3/year for irrigation and other agricultural activities.

The first part is an introduction to the volume to address the applicability of achieving sustainable agriculture in Egypt. The introductory chapter is titled "Applicability of Sustainable Agriculture in Egypt" and presents a description of the current challenges of the agricultural sector in Egypt and how we can go toward sustainable agriculture.

The second part consists of two chapters and presents some efforts to sustain sustainable agriculture under water scarcity. In the chapter "Deficit Irrigation Management as Strategy Under Conditions of Water Scarcity; Potential Application in North Sinia, Egypt," the authors introduce the results of several approaches to save water by adopting the concept of deficit irrigation. On the other hand, the chapter titled "Soil Toxicology: Potential Approach on the Egyptian Agro-Environment" addresses the toxicity of water and land from the impact of environmental pollutants, and heavy metal is another challenge for Egypt's decision-makers in the food safety sectors.

Chapters in Part III reveal the potential application of several techniques that increase crop productivity and ensure sustainability. With double cropping or two crops per year, intensive agriculture has doubled the water demand and use of relevant methods in rice production in arid regions. The chapter "Potential Role of Intercropping in Maintaining and Facilitating Environmental Sustainability" explains and proves how intercropping leads to an increment in land use efficiency and available resources, i.e., water, light, and nutrients. Also, it shows that intercropping is a successful method for avoiding pests and encouraging natural enemies and suppresses weed growth. Therefore, it facilitates yield advantage from the unit area and reduces the risk of crop production. In the chapter "Role of Intercropping in Increasing Sustainable Crop Production and Reducing the Food Gap in Egypt," the authors explain how the gap between production and consumption in Egypt could be partially solved by increasing the productivity of grain and oil crops based on adopting new crops varieties, expansion in cultivation of the new land, and the use of modern farming methods. Consequently, the extension of the application of intercropping systems which include grain and legume crops such as intercropping maize with common bean, soybean, or groundnut (as oil-legume crops) and also with cowpea and/or lablab (as forage-legume crops) is essential. Optimization of land use efficiency of the fields of cotton, sugar cane and sugar beet that are long-duration crops can be achieved through intercropping grain crops such as wheat, legumes such as faba bean, and vegetable crops such as potatoes and onions. The last chapter in this section is titled "Sustainable Cultivation of Rice in Egypt" and presents the efforts done for the increase in rice production through increased yield per unit area to meet the increasing demand of growing population despite limited resources of arable lands, irrigation water, and fertilizers.

The fourth part of this volume focuses on the ways offered by biotechnology to enhance crop productivity and therefore reduce the gap between food production and consumption. In the chapter "Bioactive Compounds in Soybean Proteins and Its Applications in Food Systems," the authors show that the bioactive protein subunits could partially or entirely replace antibiotics and other synthetic antimicrobials in different food and health applications. Thus, the maximum antimicrobial actions of these bioactive proteins could be assessed in different food systems to study the possible interactions and effects between them and food components to reach the optimal application conditions. The chapter "Influence of Natural Plant Extracts in Reducing Soil and Water Contaminants" presents the results of using *Moringa Oleifera* (MO) seed extract as a potential source for wastewater (WW) treatment due to its efficacy. The author proved that when MO is used for the treatment of wastewater, excellent results were obtained. Treatment of WW using MO seed extract is desirable because (a) they do not further deteriorate the environment, and hence they are environmentally friendly; (b) they are available; and (c) they show maximum effluent removal from both domestic and synthetic wastewater. In the chapter "Underutilized Plant Species and Agricultural Sustainability in Egypt," the author presents the concept of utilizing the underutilized plant species (UPSs) in agricultural systems as a good solution to sustain agriculture. Also, the authors indicate that many UPSs are rich in bioactive compounds, vitamins, antioxidants, oils, and protein. In fact, UPSs could play an important role in the enhancement of nutrition, health, and income for local Egyptian communities. Also, UPSs are resilient in natural and agricultural conditions, making them a suitable surrogate for the major edible plants. The chapter "Plant Biotechnology Status in Egypt" explains the biotechnology concept as connected to plants and presents the success story of biotechnology in producing several crops including wheat, cotton, maize, potato, cucumber, squash, melon, and tomato through the long experiences of Agricultural Genetic Engineering Research Institute. In the chapter titled

"Fermented Food in Egypt: A Sustainable Bio-preservation to Improve the Safety of Food," the authors focus on the effect of the implemented natural preservation on fermented products' compositional characteristics by presenting a comprehensive review on the topic.

Part V consists of five chapters dealing mainly with potentiality of soil sensing for sustainable agriculture and presents different approaches from the viewpoints of sustainable agriculture using modern technology to diagnose the state of the soil, air, and plant and then making the appropriate decision regarding the processes of reclamation and cultivation in order to increase agricultural production. The chapter "Geostatistics and Proximal Soil Sensing for Sustainable Agriculture" provides an overview of the use of geostatistical techniques and proximal soil sensing data for achieving sustainable agriculture goals. A particular emphasis was given to the on-the-go platforms especially a visible and near-infrared online platform. The chapter "Sustainable Indicators in Arid Region: Case Study – Egypt" focuses on the assessment of sustainable agricultural development according to land productivity, security, protection, validity, and acceptability as well as economic and social factor dimensions and reviews the use of remote sensing techniques and GIS as new trends in assessing and mapping sustainability degree. In the chapter "Implication of Geo-informatics (GIS/RS) on Agricultural Irrigation Management: The State of the Art," the authors provide a comprehensive overview on the implication of geoinformatics in irrigation water management on both local level (Egypt) and international level with a particular focus on geographic information systems and remote sensing. The chapter titled "Hydrological Simulation of a Rainfed Agricultural Watershed Using the Soil and Water Assessment Tool (SWAT)" aims to test the performance and feasibility of the SWAT model and TRMM for prediction of runoff in a basin with application to a study area in the Red Sea Governorate, Egypt. The author successfully demonstrates the utility of satellite-estimated precipitation (TRMM 3B43) in supporting hydrologic modeling with SWAT in Egypt. The volume ends with a closing chapter to summarize the key conclusions and the recommendations from all the presented chapters.

Much appreciation and great thanks are due to all who contributed to this volume, with special acknowledgment to the authors. 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 high-quality volume titled *Sustainability of Agricultural Environment in Egypt: Soil-Water-Food Nexus*. 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 unique volume.

Zagazig, Egypt
22 April 2018

Abdelazim M. Negm
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Introduction

Applicability of Sustainable Agriculture in Egypt

Moataz Elnemr

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Abstract Sustainable agriculture is the practices that use the resources or inputs in a way that may not affect the opportunities of coming generations to get beneficial use of these resources in the agricultural process. The gap between people needs of agricultural products and available resources in Egypt is getting wider. Sustainable agriculture can be reached in Egypt despite all obstacles and threats. Sustainable agriculture has conditions that should be met to achieve successful transition to a sustainable system. Enabling external institutions, embracing resource-conserving

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technologies should be integrated and work with local communities. Current strategies are not expected to lead us to sustainability in agriculture as it focuses on specific sectors and issues more than another's. The new strategy of sustainability toward 2030 may put wide lines of the expected beneficiaries of sustainable agriculture practices under Egyptian conditions. There is a need to create and embrace new strategies and plans to access sustainable agriculture. Farmers should share in providing information, analyzing, suggesting solutions, and implementing. Science and research should not be far from agricultural system actors. The most important is the policies that support all of these actions. This chapter gives a description for the current challenges of the agricultural sector in Egypt and how we can go toward sustainable agriculture successfully.

Keywords Agriculture in Egypt, Applicability, Sustainable agriculture

Abbreviations

ABE	Agricultural Bank of Egypt
B/C ratio	Benefit-cost ratio
ECES	The Egyptian Center for Economic Studies
FAO	Food and Agriculture Organization of the United Nations
Feddan	Local unit of land area = 4,200 m^2
GDP	Gross domestic products
GIS	Geographical information system
IEA	International Energy Agency
L.E	Egyptian pound
MALR	Egyptian Ministry of Agriculture and Land Reclamation
NEDCO	National Enterprise Development Company (Sri Lanka)
NGO	Nongovernmental organization
NRC	American National Research Council
Toe	Ton of oil equivalent (amount of energy released by burning one ton of crude oil)
US$	United States dollar = 17.85 L.E
USA	United States of America

1 A Vision for Agriculture

When going into agriculture process, there is always a question about the practices you will follow to obtain the best production with minimum inputs. Best evidence on the ability of regenerative and resource-conserving technologies and practices to bring both environmental and economic benefits for farmers, communities, and nations comes from developed countries like in Africa, Asia, and Latin America.

This comes from the emerging concern to increase food production with absence of the externally supplied technologies. In these lands, adopting regenerative technologies have substantially improved agricultural yields, often only using few or no external inputs.

This site is not the only one for successful sustainable agriculture, in very high input lands of industrialized countries; some farmers have maintained profitability while yields have fallen. These improvements have occurred in initiatives focusing on a wide range of technologies, including soil and water conservation, pest and predator management, nutrient conservation, land rehabilitation, green manuring, water management, and many others.

The answer of the question may be found in your road to manage the agricultural process in a sustainable way. Sustainable agriculture practices will result in indirect social and economic benefits. There is reduced environmental contamination and pollution, reducing the costs incurred by farming households, consumers of food, and national economies as a whole, expected less likelihood of the breakdown of rural culture. There is local regeneration, often with the reversal of migration patterns as the demand for labor grows within communities. And, psychologically, there is a greater sense of hopefulness toward the future.

2 What Is Sustainable Agriculture?

2.1 Sustainable Agriculture Definition

When we take a look on the terms that describes agricultural system, it is normal to mean different things to different people. Some may consider production possibilities or technological concentration (green revolution or complex and diverse) to the ability to adopt newly created or derived technologies. Another term may be used to describe the agricultural system is the use of inputs whether natural resources and/or external inputs. The site of keeping natural resources takes us close to the definition and goals of sustainable agriculture. Sustainable agriculture term may be used as an alternative to modern agriculture. It can be understood as an ecosystem approach to agriculture [1]. Sustainable agriculture system makes integration between the production practices having a site-specific application that will last over the long term. Sustainable agriculture is mainly related to practices that use the resources or inputs in a way that may not affect the opportunities of coming generations to get beneficial use of these resources. The agricultural system that is sustainable may be described as resource conserving, low input, and regenerative. It challenges educators and farmers to think about the long-term implications of practices and the broad interactions and dynamics of agricultural systems [2]. The technological and to lesser extent economic dimensions of sustainable agriculture have tended to be privileged, while the social dimension has been neglected. As a result sustainable agricultural has suffered from limited adoption [3].

In any discussions of sustainability, it is important to clarify what is being sustained, for how long, for whose benefit, and at whose cost, over what area and measured by what criteria. Answering these questions is difficult, as it means assessing and trading off values and beliefs. Attempts to define sustainability miss the point that, like beauty, sustainability is in the eye of the beholder. It is inevitable that assessments of relative sustainability are socially constructed, which is why there are so many definitions [4].

2.2 Some Misconceptions About Sustainable Agriculture

In addition to the problems over definitions, there are other misconceptions about sustainable and regenerative agriculture [5–7]. Perhaps the most common characterization is that sustainable agriculture represents a return to some form of low technology, "backward" or "traditional" agricultural practices. This is manifestly untrue. Sustainable agriculture does not imply a rejection of conventional practices, but an incorporation of recent innovations that may originate with scientists, farmers, or both. It is common for sustainable agriculture farmers to use recently developed equipment and technology, complex rotation patterns, the latest innovations in reduced input strategies, new technologies for animal feeding and housing, and detailed ecological knowledge for pest and predator management.

Another misconception is that sustainable agriculture is incompatible with existing farming methods. For the development of a sustainable agriculture, there is a need to move beyond the simplified thinking that pits industrialized agriculture against the organic movement or the organic movement against all farmers who use external inputs. Sustainable agriculture represents economically and environmentally viable options for all types of farmers, regardless of their farm location and their skills, knowledge, and personal motivation.

It is also commonly believed that low or no external input farming produces low levels of output and so can only be supported by higher levels of subsidies. Such subsidies could be justified in terms of the positive benefits to the environment brought by sustainable farming, which could therefore be valued and paid for. But this may not be necessary. Worldwide, many sustainable agriculture farmers show that their crop yields can be better than or equal to those of their more conventional neighbors. Even if their yields are lower, these may still translate into better net returns as their costs are also lower. Sometimes yields are substantially higher and now offer the opportunities for growth for communities that do not have access to, or cannot afford, external resources. Either way, this means that sustainable farming can be compatible with small or large farms and with many different types of technology.

None the less, when specific parameters or criteria are selected, it is possible to say whether certain trends are steady, going up or going down. For example, practices causing soil to erode can be considered to be unsustainable relative to those that conserve soil. Practices that remove the habitats of insect predators or kill them directly are unsustainable compared with those that do not. Planting trees is clearly more sustainable for a community than just cutting them down. Forming a local group as a forum for more effective collective action is likely to be more sustainable than individuals trying to act alone.

At the farm or community level, it is possible for actors to weigh up, trade off, and agree on these criteria for measuring trends in sustainability. But as we move to higher levels of the hierarchy, to districts, regions, and countries, it becomes increasingly difficult to do this in any meaningful way. It is, therefore, critical that sustainable agriculture does not prescribe a concretely defined set of technologies, practices, or policies at these levels. This would only serve to restrict the future options of farmers. As conditions change and as knowledge changes, so must farmers and communities be encouraged and allowed to change and adapt too. Again, this implies that definitions of sustainability are time specific and place specific. As situations and conditions change, so must our constructions of sustainability also change. Sustainable agriculture is, therefore, not a simple model or package to be imposed. It is more a process for learning.

What is important is to ensure that the opportunities exist for wide-ranging debate on the appropriate levels of external and internal resources and processes necessary for a productive, environmentally sensitive, and socially acceptable agriculture.

3 Goals for Sustainable Agriculture

On the global level, agricultural development policies have been remarkably successful at emphasizing external inputs as the means to increase food production during the past 60 years. This will be followed by remarkable growth in global consumption of external resources of energy, water, pesticides, fertilizer, animal feedstuffs, and farm machinery.

However, external inputs substituted the natural control processes and resources, rendering them more vulnerable. Pesticides have replaced biological, cultural, and mechanical methods for controlling pests, weeds, and diseases. Fossil fuels have substituted for locally generated energy sources. Inorganic fertilizers have substituted for livestock manures, composts, and nitrogen-fixing crops. Researchers, extensionists, and input suppliers are the main source of information which is the base of management decision.

The basic challenge for sustainable agriculture is to make better use of internal resources [8] like sun, rain, air, nitrogen, etc. This can be done by minimizing the external inputs used, by regenerating internal resources more effectively or by combining both. A sustainable agriculture, therefore, is any system of agricultural production that systematically strives to achieve the following goals [9]:

- More thorough combination of natural processes such as nitrogen fixation, nutrient cycling, and pest-predator relationships into agricultural production processes
- A reduction in the use of external and non-renewable inputs which has a great potential to damage the environment or harm the human health and a more efficient use of the remaining inputs used to minimizing variable costs
- A more equitable access to productive resources and opportunities and progress toward more socially just forms of agriculture
- A greater productive use of the biological and genetic potential of plant and animal species
- Productive use of local knowledge and practices, including innovative approaches not yet widely adopted by farmers or fully understood by scientists
- An increase in self-reliance among farmers and rural people
- An improvement in the match between cropping patterns and the productive potential and environmental constraints of climate and landscape to ensure long-term sustainability of current production levels
- Profitable and efficient production with an emphasis on integrated farm management and the conservation of soil, water, energy, and biological resources

When allowing these goals come together, farming becomes integrated, with resources used more efficiently and effectively. Sustainable agriculture, therefore, pursues the integrated use of a wide range of pest, nutrient, soil, and water management technologies. These are integrated at farm level to give a strategy specific to the biophysical and socioeconomic conditions of individual farms. Sustainable agriculture aims for an increased diversity of enterprises within farms, combined with increased linkages and flows between them. By-products or wastes from one component or enterprise become inputs to another. As natural processes increasingly substitute for external inputs, so the impact on the environment is reduced.

4 The Scale of the Challenge in Egypt

4.1 Current Strategies of Agricultural Development

Egypt is in the northeastern corner of Africa between latitudes 21° and 31° north and longitudes 25° and 35° east with a total area of 1,001,450 km^2; the country stretches 1,105 km from north to south and up to 1,129 km from east to west. It is bordered in the north by the Mediterranean Sea; in the east by the Gaza Strip, Israel, and the Red Sea; in the south by Sudan; and in the west by Libya. Agriculture remains an important sector of the Egyptian economy. It contributes nearly one-seventh of the GDP, employs roughly one-fourth of the labor force, and provides the country through agricultural exports with an important part of its foreign exchange.

The need to increase agricultural production and achieve agricultural development in Egypt is critical due to the high rate of population growth and increasing demands for food on one hand. Egypt population reached over 93 million people by the middle of the year 2017. Strategies have been set up and implemented to achieve agricultural development in Egypt. In the last 30 years, three agricultural strategies have been prepared in the 1980s, in the 1990s, and toward 2017. The 1980s agricultural development strategy dealt mainly with liberalization of the agricultural sector, pricing and increasing the annual growth rate of agricultural production.

The 1990s strategy concentrated on the completion of the economic reform in the agricultural sector, increasing agricultural exports, and increasing the annual growth rate of agricultural production. The agricultural development strategy toward 2017 concentrated on achieving self-sufficiency in cereals, increasing the annual growth rate of agricultural production, and continuing land reclamation. The previous strategies have been prepared to make a temporary development on the agricultural sector. The look of resources consumption and managing inputs for a long term was absent. The studied tendency of some environmental, social, and economic indicators toward sustainability concluded that the agricultural policy in Egypt might focus on the economic aspects and needs more attention for both social and environmental aspects [10].

Several recommendations and lessons were listed from the application of these strategies [3]:

1. Reforming pricing policies should be the base to maximizing the returns of the economic reform.
2. Further improvements are needed on the institutional reform side by side to the economic reform.
3. Applied policies in water use do not give the efficient use of water, despite the water resources scarcity. Agricultural sector consumes 81.1% of total resources. This makes the agricultural sector the first consumer of water in Egypt.
4. Enacting a clear policy to protect agricultural land from over-encroachment did not prevent violations to continue to take place.
5. Absence of policies for protecting agricultural land against fragmentation. In spite of the fact that all stakeholders agree that the fragmentation of agricultural holdings constitutes a serious impediment to development, no policy has been so far instituted for protecting agricultural land against fragmentation.
6. In spite of the successes achieved in the field of land reclamation, adding 1 ha to the cultivated area, the distribution system failed to establish viable communities capable of settling in the newly reclaimed areas.
7. Skilled labor is scarce due to the lack of balance between human resource development policies, investments, and agricultural development policies, at a time during which rural communities exhibit high rates of unemployment and underemployment.

8. Many research institutions are involved in agricultural research development, but no significant effect for their research.
9. Fisheries development policies have contradictions which created several limitations that hinder further investments in this field.
10. Policies failed to use the Egyptian geographical and historical agricultural base. There was no use to the relationships between Egypt and both African and Arab countries to obtain better marketing opportunities.
11. Cooperation and coordination between governmental and NGOs is almost lost.
12. Weak implementation and follow-up mechanisms proved the impossible to attain the objectives of the strategies even with possible attention from MALR.

It is clear that the three strategies are far from sustainability. There is a need to increase the agricultural production by 70% within 2050 in order to keep pace with population growth and changing diets. Data listed in Table 1 show some indicators about the agricultural sector in Egypt to be compared in the years 1965, 2000, and 2014. In spite of the need to increase the production, the increase in agriculture lands does not give a reassured indicator to cover the needs of population which increased to doubles of agricultural land increase. This could appear in the arable land per capita which reached 0.03 ha/person which means a decrease in the opportunities of agricultural production to meet the needs. In addition, the value added of GDP decreased by 61%. This is considered as a strong indicator to the failure of the running strategies in making a significant development in the Egyptian agricultural sector or even keeping the situation as it is. The absence of social policies to keep qualified labors serving in the agricultural sector clearly appears in the percentage of male employed in agricultural sector. This decrease in male employment was replaced by the increase in female employment in agriculture. Egyptian social structure indicates this replacement is just for keeping labors' families income. Women in Egypt are not supposed to have the same skills or experience of men. This means that the agricultural sector lost the ability to attract labors that preferred to find another activity as a source for their income. There is an urgent need for social policies in farm areas to encourage people to go into agricultural activities.

Table 1 Changes of the agricultural sector indicators in Egypt since 1965 till 2014 according to the calculations of World Bank

	1965	2000	2014
Total population, millions	30,872,982	68,334,905	91,508,084
Agriculture land (% land area)	2.68	3.31	3.76
Permanent cropland (% of land area)	9.65	0.492	1.08
Arable land (% of land area)	2.59	2.81	2.68
Arable land (hectares per person)	0.08	0.04	0.03
Value added (% of GDP)	28.6	16.74	11.18
Employment in agriculture (% of male employment)	NA	27.4	24.1
Employment in agriculture (% of female employment)	NA	39.4	42.9

It is clear that Egyptian agricultural sector is in a real need for different planning strategies toward sustainable agriculture. Current planning strategies till 2017 did not consider the required integration between social, economic, technical, and environmental faces of the agricultural sector but tried to make fast solutions for specific issues. As mentioned before planning for a regenerative system needs a long-term vision, or degradation on all the agricultural sector components is expected.

4.2 Challenges of Agricultural Sector in Egypt

4.2.1 Resources Mismanagement

Egypt is facing unprecedented resource crisis: in energy, water, and arable land. Total energy production in Egypt increased from 53,090 to 80,357 ktoe during the period between the years 2000 and 2014. The agricultural sector consumption of energy increased 751.3% during the same time period according to the statistics of IEA. In spite of this increase, 17% of Egyptians still suffer from food insecurity [11] which means the energy use in the agricultural sector is inefficient as it did not make remarkable increase in agricultural production. The agricultural sector comes first at water resources consumers as it uses 81.1% of total water resources. Most of Egyptian lands are irrigated with surface irrigation system especially in Delta region. 85% of irrigation systems in this region is based on surface irrigation [12] which has no control on the amount of applied water and managed by the farmer's experience and far from scientific management bases.

Small holders' farmers are about 81% of total farmers. The average of agricultural land holding in Egypt is 1.26 ha; this means that most of arable lands in Egypt are uneconomic units. As a result farmers will try to go through another activity may be followed by soil dredging.

4.2.2 Marketing and Rationing Policy

Pricing policies of agricultural products may hinder farmers to cultivate important crops like cereals. Rationing policies are based mainly on export for cereals, red meat, forage, sugar, and oil. As a result of these policies, the Egyptian net agricultural trade according to World Bank statistics reached −9,284,28 million US$ in 2010. Generally, activities of value chain [13] under local Egyptian conditions are losing control. There are no regulations for human resources management like training or hiring. Absence of supportive activities like infrastructure, accounting, finance, quality assurance, and technological development is another reason to lose control on marketing. Lack of organized central markets and low level of marketing services makes it difficult to exchange and trade food products among Egyptian governorates.

4.2.3 Poor Planning for Implementing Modern Technologies and Agriculture Practices

Implementation of modern technologies not only related to the direct implementation or the percentage of farmers who tried to use modern technology. For example, a number of used tractors increased from 307,944 in the year 2000 to 390,568 by the year 2008 according to World Bank statistics. This increase should be an advantage to increase production and better field management. With the small tenure which does not exceed 1.26 ha (refer to the Sect. 4.1), it may turn into uneconomic practice. Another example related to modern irrigation systems which are recommended by many studies to replace surface irrigation system [14–17]. This replacement is considered a must with the current water scarcity situation. The cost of these systems is the first obstacle for the farmers to apply this technology.

Another example may be found with agricultural chemicals; most of farmers use chemicals like fertilizers and pesticide to increase their production. Wrong use of these chemicals made a lot of healthy problems because of the highly polluted products beside the expected contamination of the soil itself. This problem is also related to the low qualification levels of the farmers and labor beside the absence of extension role. Despite the need to increase the production, this increase will have to be achieved in a way that preserves the environment. The use of pesticides and plant nutrients like nitrogen and phosphorous should be used in such a way to minimize the emissions of greenhouse gases [18]. One of the threats which face the application of modern technologies in the Egyptian water sector is lack of information or non-dependency on databases to make decisions, policies, and managing agricultural practices. The wide frame of this scene shows that agriculture modernization is self-practice not following certain plan or strategy and this can't give any expected positive impact toward sustainable agriculture.

4.2.4 Weak Support to the Food Industries Sector

Agriculture-based industries are not just related to the quality and quantity of the products, but also related to the logistic services introduced to this sector. Food industries sector contributes 11% of the GDP with total investments 500 billion L.E [19]. This number reflects the importance of this sector to the national economy. At the same time most of the factories are still far from the cultivation areas and concentrated near to the capital or large cities that have industrial zones. This creates the need for better transportation utilities and infrastructure. Policies should consider also facilitating flow of capitals, organize competition between producers, and open export markets. Whenever strong was the food industries, this will encourage farmers to improve their products in addition to encourage investors to go through the agricultural sector itself.

4.2.5 Lack of Necessary Infrastructure

Most of arable lands are near to villages which still suffer from lack of drinking water supplies, sewage stations, transportation, and roads. Even the large area farms in the west of Egypt still suffer from absence of energy supplies, central markets, and some necessary services like huge refrigerators. Wheat is considered a clear example on how the weak infrastructure affects the possibilities to reach self-sufficient of agricultural production. Annual wheat production heat production is about 9.46 million ton faces needs of 18 million ton. Silos can accept till 6 million tons. They are not enough to accommodate the local production or the imported quantity. According to World Bank statistics, cereal lands increased from 2,614,460 to 3,291,950 ha from year 2000 till 2014 in Egypt. There is a direct threat that the current storage capacity of silos may prevent proposing to increase the strategic reservation or annual production of wheat and cereals in general.

5 Reaching Sustainable Agriculture and the Record of Modernized Agriculture

5.1 Types of Agriculture Systems

The modernization of agriculture has resulted in the development of three different types of agriculture. The three types are industrialized agriculture, Green Revolution, and diverse, complex, resource-poor systems. Industrial agriculture is a form of modern farming that pointing to the use of agricultural productions in industry, including livestock, poultry, fish, and crops. The methods of industrial agriculture are techno-scientific, economic, and political. The Green Revolution was a period when the productivity of global agriculture increased drastically as a result of new advances. This was due to new farming practices implementation comprising the use of new chemical fertilizers and synthetic herbicides and pesticides. The chemical fertilizers made it possible to supply crops with extra nutrients to increase the yield. The newly created synthetic herbicides and pesticides controlled weeds, deterred or killed insects, and prevented diseases.

Green Revolution included genetic technology, innovation in agricultural machinery and farming management methods, techniques for achieving economies of scale in production, the creation of new markets for consumption, the application of patent protection to genetic information, and global trade. Yield levels by applying these systems showed that industrialized systems have the greatest indicative yields followed by Green Revolution and finally diverse systems. Involving sustainable agriculture practices will cause higher yields if compared to the existing systems all over the world [9]. The first two types may not be compatible with the current agriculture system in Egypt, but they are still able to respond to the technological packages, producing high output systems of agriculture in the industrialized countries and in the Green Revolution lands. The third type comprises all the remaining agricultural and livelihood systems which are the low input systems, complex and diverse, with considerably lower yields. This system may be near to the Egyptian agriculture system. In general, not all the countries of the third world untouched by modern technology. Some 2.3–2.6 billion people are supported by agricultural systems characterized by modern technologies brought by the Green Revolution. These systems have good soils and reliable water and are close to roads, markets, and input supplies. The area of these lands is some 215 million ha, and they currently produce 60% of the grain in Third World countries. Alternative sustainable systems in these regions have been able to match their yields and profitability. On the other hand, 1.9–2.2 billion people are largely untouched by modern technology (based on estimates from FAO and World Bank data). They tend to be in the poorer countries with little foreign exchange to buy external inputs. Their agricultural systems are complex and diverse and are in the humid and semi-humid lowlands, the hills and mountains, and the drylands of uncertain rainfall. They are remote from services and roads, and they commonly produce one-fifth to one-tenth as much food per hectare as farms in the industrialized and Green Revolution lands. It is in these regions that sustainable agriculture has had the greatest impact on local food production so far, with yields doubling to trebling with little or no use of external inputs. Referring to the character of such countries, we can say Egypt is one of those countries. At the same time, we can’t say that lack of technology is the only reason to be in this situation. Mismanagement and poor planning play the greatest role to reach this situation.

Agricultural modernization process has had many impacts. These include the loss of jobs, the further disadvantaging of women economically if they do not have access to the use and benefits of the new technology, the increasing specialization of livelihoods, the growing gap between the well-off and the poor, and the co-option of village institutions by the state.

Despite the expected improvement through these modern technologies, all too often there are adverse environmental and social impacts. Many environmental problems have increased dramatically in recent years. These include:

- Contamination of water by pesticides, nitrates, and soil and livestock wastes, causing harm to wildlife, disruption of ecosystems, and possible health problems in drinking water
- Contamination of food and fodder by residues of pesticides, nitrates, and antibiotics
- Damage to farm and natural resources by pesticides, causing harm to farm-workers and public, disruption of ecosystems, and harm to wildlife
- Contamination of the atmosphere by ammonia, nitrous oxide, methane, and the products of burning, which play a role in ozone depletion, global warming, and atmospheric pollution
- Overuse of natural resources, causing depletion of groundwater, and loss of wild foods and habitats, and of their capacity to absorb wastes, causing waterlogging and increased salinity

- The tendency in agriculture to standardize and specialize by focusing on modern varieties, causing the displacement of traditional varieties and breeds
- New health hazards for workers in the agrochemical and food-processing industries

Despite these problems, many scientists and policy makers still argue vigorously that modern agriculture, characterized by externally developed packages of technologies that rely on externally produced inputs, is the best, and so only, path for agricultural development. Influential international institutions, such as the World Bank, the FAO, and some institutions of the Consultative Group on International Agricultural Research, have long suggested that the most certain way to feed the world is by continuing the modernization of agriculture through the increased use of modern varieties of crops and breeds of livestock, fertilizers, pesticides, and machinery. Remarkably, these international institutions often appear unaware at policy level of what can be achieved by a more sustainable agriculture. However, there are some signs of change, mostly limited to small groups of individuals, plus some small modifications in policy.

The FAO has estimated that over 50% of future gains in food crop yields will have to come from fertilizers. This calls for massive increases in fertilizer consumption by poor countries.

Traditional agriculture is presented as environmentally destructive, so needing to be modernized, or as efficiently managed systems which have hit a yield ceiling, so again needing modern technologies. Even where there have been recent shifts in emphasis, both in rhetoric and substantive policy, the Green Revolution model tends to be widely believed to be the "only way to create productive employment and alleviate poverty" [20].

5.2 *Stagnating Capacity in Modern Systems*

Modern agriculture has remarkable impact in the Third World countries. The modernization exampled in planted modern varieties of wheat and maize and growing consumption of fertilizers, nitrogen, and pesticides. As a result, food production per capita has, since the mid-1960s, risen by 7% for the world as a whole, with the greatest increases in Asia, where per capita food production has grown by about 40% [21]. In Egypt, there are a lot of tries to obtain the positive impact of modern agriculture. These tries included:

1. Creating high-productive varieties for rice, maize, cotton, wheat, and some other crops
2. Creating highly resistive varieties against diseases and climate change
3. Building up a gene bank to protect the genetic specifications of Egyptian crops
4. Genetic improvement of local breeds of ruminants and poultry
5. Conservation and dissemination of improved local genetic resources from animals and poultry

6. Making scientific studies on the effects of climate change [22]
7. Improvement of irrigation infrastructure and going toward modern irrigation systems
8. Utilization of climate data, GIS, remote sensing in agriculture, and water sectors

Even though all of these did not get the significant impact on the agricultural sector in Egypt, many challenges are still facing the efficient application of such modern practices (refer to Sects. 4.1 and 4.2).

The application of modern agriculture is expected to decrease the gap between the need of food and increased population. In addition, these practices will give the increase in yield which is more important than the increase on cultivated lands [20]. The description of this situation is that science-based agriculture is the key to permit higher and more stable production, ensuring food stability and security for a constantly growing world population [23].

It is still possible that new technologies, such as biotechnology and genetic engineering, will open up new frontiers. Scientists hope that these will produce crops and animals that are more efficient converters of nutrients, with better drought tolerance and pest and disease resistance. One dream has been the incorporation of nitrogen-fixing nodules into the roots of cereals, so making these crops self-sufficient in nitrogen. If such breakthroughs do occur, it will be important that ways are found to ensure their availability to poorer farmers. If they are still part of a package, or rely on hybrid seeds that must be repurchased after every replanting, then they are likely simply to encourage even greater dependency on external resources and systems and open up gaps between wealthy and poor farmers. Those low-income countries that are currently poorly endowed with natural resources and infrastructure are unlikely to benefit [24].

6 Science and Sustainability

Traditional agriculture is still the dominant paradigm. The word sustainability should be the core element of decision-making, government policies, university research projects, and extension organizations. The results of the strategies of agriculture did not make satisfaction about their implementation. Sustainability is a challenge but it is not the only challenge for agriculture. Climate change, replacing fossil fuels with renewable energy, is relatively new challenges. In general, two broad paradigms of sustainability are identifiable: first one supports systems-level reconstruction of agricultural practice to enhance biological activity and the other adopting a technological fix, in which new technologies inserted into existing systems can improve sustainability outcomes [25].

Reaching sustainability is based mainly on understanding the required links between nature and human action [26]. This gives us a vision on how many sciences should be linked together while searching sustainability. One of the keys to reach sustainability is that no exact science should be forwarded on another. All sciences stand on one line on the road of sustainability.

A Question May Appear in Our Minds: Is There a Sustainability Science? Yes, sustainability science is "a modern field of research transacting with the interactions between natural and social systems." From this definition we can understand that sustainability science is a combination of sciences related to nature and human life. It is also necessary to understand how these sciences can interact to solve the challenge of sustainability and meet the needs of current and future generations while reducing poverty and conserving life support systems [27]. We are in need for balancing human needs with keeping and improving ecosystems ability to provide the goods and services. In a simple way we can reach this by increasing goods and services or by reducing the consumption. In fact doing both is a result for well-planned sustainable system. Understanding the role of each science in sustainability is very important for the necessary integration of biophysical and social sciences that shapes sustainability science.

Successful applications of sustainable agriculture are still not widely spread worldwide. Despite the existence of such practices, only few farmers have adopted new technologies and practices. Sustainable agriculture definition and general concept are deeper and more fundamental challenge than policy makers, researchers, and extensionists may assume. Sustainable agriculture is not just related to specific practices or using modern technologies. It needs technology and knowledge transfer between farmers and professionals, external institution support, local group support and cooperation, efficient resources management, and above and first of all agricultural policies to support all the previously mentioned elements. It needs also a close view to the way we conceptualize and achieve sustainability. Many researchers studied the performance of modern agricultural machines, irrigation systems, farm management practices, etc. They usually recommend using a specific technology or technic that may increase the yield or enhance a feature of any of the agricultural systems components. At the same time they may neglect the economic side of this use or did not mention how the local community can approve this. A study had taken place to compare the hydraulic performance of some emitters of drip irrigation system to find how can emission uniformity affects the sustainable management of such kind of irrigation systems [28]. Results showed that there is a type of emitters gave the greatest water use efficiency, energy use efficiency, and better hydraulic performance. But this type did not give the greatest B/C ratio which is considered the most important indicator that concerns farmers. Science takes its importance from continuous trials to discover the reality, predicting and controlling natural phenomena.

Complex world will be sliced into small parts that will be analyzed and interpreted to make predictions about these parts. This knowledge will be integrated again; then we can know about the world. In this context, investigators can't live away from the world to reach the truth. Knowledge about the world will be summarized to take the universal form. With a high degree of knowledge and control over a studied system, we can say we have a true knowledge which equals good science.

This positivist approach has generated the application of technologies by farmers. As mentioned above, researchers try to simulate the reality to find solutions and give recommendations to deal with a natural phenomenon. Researchers can access all the required inputs, while farmers are controlled by many factors whether natural, economic, and social or any other effect.

Applying modern agriculture in this case may stop in the research station. It is not necessarily that the best performing farmers can obtain the same yield obtained by a researcher. When researcher has access to all necessary inputs at appropriate time, farmers do not have the same ability to reach the package of getting the highest yield. When one element is missing, the whole process will fail.

A Truth About Science

To suggest a solution for a certain problem in scientific way, you should detect the problem and try different solutions to pick the most suitable one. View to the problem will vary greatly from one to another stakeholder in the agricultural system. When trying to recommend solution, the variation in how feasible is it will be greater and more complicated. No scientific method can find a solution that makes complete satisfaction to all the people involved in the system. It is seriously misleading that scientific knowledge and method traditionally embrace uncertainties enthusiastically and exhaustively pursue them [29].

Data collected for a scientific purpose should be objective and value-free. The context of the data affects the outcomes, but you can ignore the context when the data is objective and true.

Selective samples of any study may make what is near to a disaster when depending on their results in decision-making or planning long-term strategy. An example for this was 22 erosion studies in the Upper Mahaweli Catchment in Sri Lanka concerning mid-country tea that have taken place [30]. There was untraditional variation in the estimates of erosion between 0.13 t/ha/year and 1,026 t/ha/year [31–33]. The lowest estimate was by a Tea Research Institute to show how successful and safe they are managing the soil. High estimate was by a developing agency showing how serious is the erosion problem in the Third World. This great variation in estimates and results running in the context of an organization purpose indicate how you can be merely selective and not lying.

Another example was about water use and energy needs described by [34]. The projections of the needs were based on data collected in the northwest of the USA. First projection showed a growth need of energy to the year 2000; second projection showed downward trend. First projection was conducted by an energy providing company, while the second was by environmental groups. In addition projections made by consultancy groups were found in the center.

This should not open the door of doubt about the reality of data. Data should not also be descriptive to the nature of organization, institution, or group who show the data. In both of the two previously mentioned examples, projections were logical and internally elegant. But here you are using specific methodology, sampling, and measuring techniques to introduce our data and recommendations to specific audiences or actors that play a role you need. The great challenge we are facing here is to make agreements between all the actors or stakeholders in the agricultural process. All of these actors have their own agenda and waiting to be served by science to introduce solutions in a way they are interested in it. Science can't serve sustainability if there was no sufficient survey to the needs of sustainability elements (see Sect. 7.1) to solve problems.

The road of science we are following to define and solve problems is straight. The fact is this road is squiggly. Another face of this problem is we have to follow this winding road to access the facts required to deal with problems [35].

When trying to solve problem and doing an act to make change to reach better situation, we need pluralistic ways of thinking [29, 36–43].

Positivism [44] may introduce suitable philosophy to use science in sustainable agriculture research. For both natural and social sciences, positivism assumes that real knowledge comes from physical experiments which will be then analyzed and processed. This paradigm of scientific philosophy studies the properties of any phenomena and the links between it and other ones. This theory is near to the philosophy and nature of sustainability because of the integration between sciences and linking phenomena.

Despite this rapprochement between positivism and sustainability, many scientists still see that information should be interpreted by public and policy makers. By the meaning, positivism makes nature the source of information and idea, while some scientists see the science itself is the source of information, and they are free to choose what to study and show the results to the public.

Following any of the ways to find the "truth" of something is related to the way we think about methodologies for finding out about our environment. Sustainable agriculture practices are dynamic and complex, and no certain way whether positivism or reductionism can simplify these practices [41].

There are five principles set out the main differences between positivist science and other paradigms in sustainable agriculture implementations [45].

1. The belief that sustainability can be accurately defined is flawed. Sustainability concept does not indicate fixed set of technologies or practices. Each stake holder has different values. This is a part of the problem that sustainable agriculture is not a specific farming strategy or certain scientific methodology, but it is related to what we are trying to achieve. An example for this principle may be clear in the strategies of Egypt from 1980 to 2017 to reach sustainable agriculture. They may be based on scientific studies, but they have very wide titles and concerned on specific issues so we can say they were far from a scientific paradigm that leads to sustainability.
2. All actors have their own point of view and try to explain their problems in a unique way. This is also identical to their tries and suggestions for finding solutions and makes improvement. We should deal with the fact that there is no single correct understanding because it is related to believes, understanding, framework, and personal knowledge which are socially constructed. It is essential to deal with a problem with different views from involved actors.

3. Solving one problem may create another problem. We have to consider collecting large amount of data before reaching certainty about an issue. This is one of the impacts of positivism. One of the examples in Egypt may be taken from the lack of energy resources. Egypt is rich in solar radiation and many studies succeed to use solar power in farm applications like irrigation machines and greenhouses environment control. There may be a reduction in energy cost, but the capital cost of solar cells does not encourage normal farmers to convert to using this source of power. Here an economic and social studies have to be done in parallel with power studies.
4. Continuous learning for the actors enables them to accept new technologies and deal quickly with any change in conditions. Wider knowledge encourages improvements in technologies and practices as they are supposed to be accepted by the farmers.
5. Systems of learning and interaction like extension systems are required to encourage greater involvement of all the agricultural system actors.

We can conclude from this that it is may be not expected but human is the most important element that controls dealing with problems. Human education, experiences, skills, the way they see the problem, and the way they accept solutions are limitations for scientific approach we are following to detect and solve issues. Data about any problem should be collected from all the actors of the problem, and the description of problems should be in agreement or in between with their views.

Also solutions have to be accepted to be implemented through actors. Research may find best solutions but if not accepted by actors, it loses its beneficiary. We need to make development in research to combine discovering dynamic and complex situations and taking action to improve them by making actors and stakeholders involved as companions in the whole process [46].

Making human involvement in solutions may open the door to clarify unique properties of information required in agricultural sector. Changeability and local validation are two general specifications of information. When looking to these specifications in the agricultural sector, we see that they transform to be more critical. The change of information in agricultural sector is because it is related to many other conditions like marketing, human resources skills, education, climate change, and last but not least political situation. Also the nature of a certain problem may vary from a territory to another, and so there will be differences in description. As a result information should be locally valid and collected.

In Egypt many studies have been done to discuss agriculture sustainability [10, 22, 47, 48], and of course there are hundreds of studies on agricultural practices and how to improve them to increase crop production and conserve resources. The problem is not related to the topic of studies or quantities. The question is how these studies can go into implementation framework to give beneficiaries to the stakeholders.

Educational institutes and organization should consider the need of professionalism in agriculture. They should be able to train and transfer the knowledge to professionals and make them able to deal with farmers or work with them.

Sustainable agriculture policy in Egypt has to give the opportunity to science and scientist to go out toward implementation not jailed in conferences and papers.

7 Conditions for Sustainable Agriculture

7.1 Successful Transition to Sustainable Agriculture

Understanding the challenges for sustainable agriculture is the right start to access it. Of course the challenges are different from a region to another. We may now are in agreement that Egypt is following the diverse and complex lands type of agriculture. The main challenge here is how to increase the yield per ha while keeping natural resources.

Sustainable agriculture can be reached in any of agriculture systems. In the diverse, complex, and resource-poor lands, embracing regenerative technologies may double or triple the yield. This can be side by side to the use of little or no external inputs. A problem may appear here about if the farmers get more output from less output. The answer may lead us to the main problem of planning and making strategies to reach sustainable agriculture in Egypt. The plans try to solve the problems without any try to change the current barriers. Nature and level of the Egyptian farmers' knowledge, labor skills, field and resources management practices are picturing essential elements in the agricultural process that in need to change but we are dealing with them as constants. When resource-conserving technologies are developed, they should be used by local groups and institutions, and both should be supported by external research. Sustainable agriculture can't be reached unless the three elements worked together Fig. 1.

Favorable policy environment and successful strategy can link the three elements together. Missing these elements will lead to failure of reaching a sustainable system. Policies and strategies in Egypt till 2017 are still missing the linking mechanism between sustainable agriculture elements. In best case the policy frame work will encourage going to increase external inputs or modern technologies without planned steps to convey this to the farmer. Farmers also need to improve their knowledge about modern farming. Also labors need to enhance their skills to deal with modern farming practices.

They have made use of resource-conserving technologies, such as integrated pest management, soil and water conservation, nutrient recycling, multiple cropping, water harvesting, waste recycling, and so on. In all there has been action by groups and communities at local level; and there have been supportive and enabling external government and/or nongovernment institutions. Most though are still localized. They are simply islands of success. This is because a fourth element, a favorable policy environment, is missing. Most policy frameworks still actively encourage farming that is dependent on external inputs and technologies. It is these policy frameworks that are the principal barriers to a more sustainable agriculture.

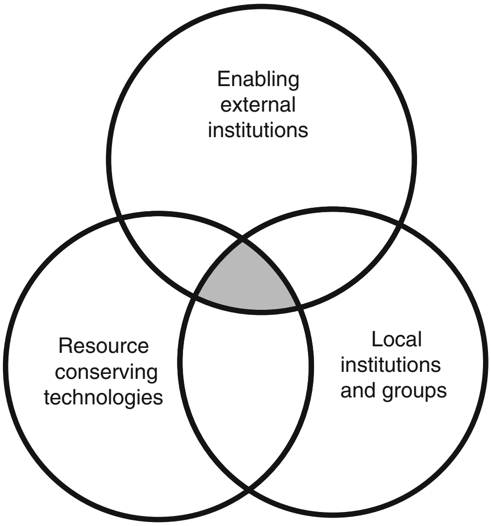

Fig. 1 Conditions and elements of sustainable agriculture [9]

It should be understood that transferring to sustainable agriculture is not a win-win relationship. There are always winners and losers. The idea here is to avoid repeating the same planning mistakes and nominate a category of actors or give an element of sustainable agriculture less care.

The change may face many threats but this will be solved by changing policies. For example, the target of exporting agricultural production is directly related to the international markets policies. Any decrease in commodity price will reduce the net benefits of farmers. This will not be followed by a decrease in the price of chemicals or farm tools, for example, because local companies are trying to keep the prices of their products. Farmers themselves face transition costs of adopting sustainable agriculture practices and technologies and acquiring new management and learning skills.

7.2 Resource-Conserving Technologies and Processes

Integrated pest management, nutrient management, water and soil conservation, and multiple cropping are examples of resource-conserving technologies. The adoption of these technologies results a favorable changes in the farming system. For example, there is an encouragement of rice farmers to grow fish in rice fields. This practice means low consumption of external input like nitrogen as the wastes of fish will do the same role. In addition the final benefits of unit area will increase. This implies that the resource-conserving technologies are multifunctional.

Integrated pest management does not mean only the reduction of pest population. It is also the way to find suitable strategy to make pest control sustainable and friendly to the environment. Nutrient conservation may also be easy to implement by using manure as local nutrient. This means that farmers should give better care to their cattle health to ensure sufficient and qualitative local nutrient.

Following these practices looks more complicated than following a schedule for spraying and using chemicals. It requires basic training and analytic skill and the capacity to monitor on-farm ecological processes. Without training and increasing farmers knowledge, all these practices will keep its position just in research papers. Farmers should be convincing with the importance of these practices specially it is expected to reduce their benefits on the short term. Agricultural extension role appears here to transfer the knowledge and clarify all the opportunities and threats of implementing such practices. With appropriate incentives, farmers may be capable of applying such practices.

Policy makers and farmers need to realize that these biological processes which include rebuilding of stock of natural predators and wild host plants, increasing the levels of nutrients and improving soil structure, and the establishment and growth of trees need time to be established and work as a sustainable agriculture practice.

7.3 Local Groups and Institutions

Successful sustainable agriculture not only based on the knowledge and skills of the farmers and labors. Participation and cooperation between farmers are required. Collective action of household farming is necessary for mainly two possible reasons. First, conventional farming system which causes resources degradation conveys this harm to the sustainable system. Second, sustainable system is expected to produce goods which can be diminished by the lack of support of tradition systems.

Motivation and coordination between farming households are necessary conditions for sustainable agriculture. These include pest management, soil and water conservation, nutrient management, livestock management, and controlling groundwater pollution.

There is a need to establish platforms for collective decision-making. Absence of such platforms to manage the global decision-making is a problem facing sustainability [43].

Local groups or institutions can be found in six shapes that are relevant to sustainable agriculture [9]:

- Community organizations
- Natural resource management groups
- Farmer research groups
- Farmer to farmer extension groups
- Credit management groups
- Consumer groups

Community organizations: They are mainly concerned with community development. The role of these organizations in Egypt in the agricultural sector is limited to introduce financial support for farmers. Recently some of this organizations turned into profits organizations dealing with all kinds of people. There is a complete absence for organizations that introduce training and extension services for farmers. Even services introduced by Egyptian government like health care is introduced to the small residential communities that are mostly located in villages but not focusing on farmers themselves.

Natural resource management groups: Some of agricultural areas in Egypt suffer from lack of natural resources like water. Farmers in these areas make a local management group to manage the operation of irrigation. They may share the costs of digging well(s) or pumping plants and make rotation between each other's to use water delimited by time and date.

Farmer research groups: As mentioned before, research should start from the people and their share by problem identification, analysis, planning, suggesting solutions, and implementation side by side to researchers and extension staff. Farmer research group makes researchers know fast and accurately about agricultural problems.

Farmer to farmer extension groups: When relying on experience, transferring knowledge from farmers is greatly easier if transferred by researcher or extensionists. It is easy to farmer to understand what are the questions and ideas occupying his colleagues head. Training farmer as extensionists may introduce a good solution to transfer newly obtained skills and information.

Credit management groups: They have the responsibility to manage granting credits. This function should be done under the umbrella of banks. The lack of the effective role of credit managers is evident in the legal problems that faced farmers recently because of loans and financial support introduced by banks. The ABE which is the destination of most farmers does not have its own policy which should be suitable for farmers' conditions not as any normal bank.

Consumer groups: Introduce great opportunity to give feedback about the quality of agricultural products and share information about markets. They may suffer from lack of organized communication mechanism so it will be self-belt.

7.4 Enabling External Institutions

Local people should be engaged in data collection, decision-making, analyzing, and improved practice implementations. There are benefits if people share in decision-making and analysis and provide information. In general the share of people can be passive if just they are told what will happen. We can turn this share into positive one by giving them the opportunity to feel that their opinion are valued and the have incentives. Incentives encourage farmers to obtain more knowledge, improve their skills, provide resources such as labor, and able to contribute financially. When incentives are absent, people lose their stake in sharing in the agricultural process.

People participation expression is normal to be used by development agencies because of its importance. When people are well organized, they should be encouraged to form groups.

When planning to reach sustainability, the interactive participation of people is a must. In such planning people engage in joint planning and formation, which leads to form new institutions or make the existing stronger.

It tends to integrate different branches of knowledge with structured learning and show perspectives. Sustainable agriculture should create new ways of learning about environment. We should not be confused between learning and teaching. Transferring from teaching to a learning style has deep effects on agricultural development institutions.

Central to sustainable agriculture is that it should enshrine new ways of learning about the world. Learning should not be confused with teaching. A move from a teaching to a learning style has profound implications for agricultural development institutions. The focus is less on what we learn and more on how we learn and with whom [41]. Sustainable agriculture implies new role for development professionals, and this is related to make a new professionalism concepts, values, behavior, and methods [49]. The issue of learning should be about what and how we learn with whom [41].

7.5 Supportive Policies

Policy makers and the state play an important role in sustainable agriculture. Any interaction from any of the stake holders in the agricultural system needs support from governmental policies. Governmental policies also have the ability to make all interactions and development tries more easily through the following steps:

1. Government can make a mix of policy instruments and measurements.
2. Make decentralization of administration to facilitate reaching and communication with local people.
3. Create a framework to manage land tenure and resources.
4. Making institutional framework which is sensitive to the people needs.
5. Developing suitable marketing policies to increase the efficiency of using resources.
6. Giving incentives of conserving resources and pollution decrease.

If the policies are not well planned, they will give reverse effect. Policies should be designed to make integration between farm, community, and national levels.

8 Applicability in Egypt

Sustainable farming can be compatible with small or large farms and with many different types of technology**.** From this point we can say sustainable agriculture is applicable in Egypt. We discussed in the previous sections the challenges of the agricultural sector in Egypt and condition to reach the sustainable system. Current strategies and policies push the agriculture sector far from sustainability. Sustainable agriculture can have wider benefits. But this does not in itself indicate how it may be adopted by farmers worldwide. It suggests there can be many winners, but it is not clear who will be the losers in the short term. All successes have had three elements in common and there is much to be learnt from these. First, all have made use of locally adapted resource-conserving technologies. Second, in all there has been coordinated action by groups or communities at the local level. Third, there have been supportive external (or nonlocal) government and/or nongovernment institutions working in partnership with farmers.

On the road to sustainable agriculture, a new strategy has been prepared in Egypt to convert agricultural policies and plans to sustainability by the year 2030. It may be the first strategy that considers the integration and links between sustainable agriculture system elements. The main aims of this strategy are as follows [3]:

1. Sustainable use of agricultural natural resources
2. Improving agricultural productivity
3. Increasing competitiveness of agricultural products
4. Achieving higher rates of food security in strategic goods
5. Improving opportunities of agricultural investment
6. Improving livelihood of rural inhabitants

These objectives will be through implementation of some mechanisms to make significant modifications in the agricultural sector and all involved stakeholders and agricultural system components [50].

Current agricultural system in Egypt is a diverse, complex, resource-poor system. To reach the success of these changes, they should be technically, ecologically, economically, and socially approved. A low number of learners and poor quality of education in Egypt make it hard to convey the modern technology and research recommendations to farmers. Environmental problems do not occupy the required importance level in farm practices. Unsafe way to dispose farm residues and high concentration of chemicals and heavy metals in water and soil are considered most serious and dangerous environmental problems in the Egyptian agriculture sector, for example, a farm residue like rice straw getting disposed by burning despite various available uses of this waste. Profusion in using chemicals because of lack of training and experience has also affected the quality of soil and water. As a result kidney and liver diseases are concentrated in the agricultural area. We should keep away from the impractical technologies that farmers can't adopt [51].

We will introduce an example on the considerations of making policy changes. It is known that the agricultural sector is the greatest consumer of water resources in Egypt [52]. The main reason of this situation is the current depend on surface irrigation system which is also managed in bad way. Till now modern irrigation system did not succeed to replace this system. If we made a comparison on which system can be applied under Egyptian conditions, we will find that surface irrigation system will achieve superiority over modern systems as shown in Table 2. From the technical side, surface irrigation system does not need high skilled labor contrary to modern systems. On the environmental seen Lack of farmers' awareness of water scarcity makes the ability of modern systems in saving water out of their consideration. In addition there is no price for irrigation water, so any talk about water crises does not make effect because the reply will be "It's free." The high capital cost of modern systems prevents most farmers to use it even they are convinced with its importance. Small holding area makes it hard to cover the cost of modern systems in short time period. No certain problem may face both systems to be socially approved. When we try to solve this, we will find a need to improve labor and farmer skill to deal with modern systems. This requires improvements in the educational and extension systems.

Also we need to give farmers financial support or make investments.

This is an example of one of many issues related to the conservation of natural resources which made us trying to solve many problems before expecting its successful implementation.

Sustainable agriculture strategy toward 2030 is expected to increase the total returns of land and water units as shown in Table 3.

On the other hand, all of these beneficiaries can't be reached if any of the actors in the system played his role individually. This is one of the obstacles of applying

Table 2 Comparison between applicability of surface irrigation system and modern irrigation systems considering Egypt's conditions

Surface irrigation		Modern irrigation
Yes	Technically	No
Yes	Ecologically	In between
Yes	Economically	No
Yes	Socially	Yes

Table 3 Expected benefits of applying the Egyptian strategy toward 2030

Description	Measuring unit	2007	2017	2030
Water qualities anticipated to be used	10^9 m^3	58	61	64
Projected land area	10^6 Feddan	8.4	9.6	11.5
Cropped area	10^6 Feddan	15.4	19.2	22.9
Percentage of intensification	%	183.6	199.1	200
Index of the increase in the returns of water unit	%	100	168	218
Average rate of return of the land area (Feddan)	10^3 L.E	13.2	20.3	22.9
Index of the increase in the returns of the land unit	–	100	154	174

sustainable agriculture practices. Too many people are required to follow the same plan, and alternatives should be ready for any role absence or bad application.

Despite the expected success of modern systems and the recommendations of using external inputs [53, 54], it does not seem that Egypt is able to turn into this model directly. We need to set the three sustainable agriculture conditions together first and expect widely self-spreading. After achieving this, policy makers can plan to turn to the Green Revolution model which can involve small- and medium-sized farms to be driven by productivity-enhancing technological change. This can offer a way to create productive employment and alleviate poverty on the required scale [20].

9 Conclusion and Recommendations

Sustainable agriculture can be applied and reached in the Egyptian environment. To reach sustainability, we should ask from where to start and what you want to access. Sustainable agriculture is accessible with small holding areas and poor resources. Sustainable agriculture is not related to a specific situation, but about how you can achieve its conditions and what strategies and policies you will follow with which mechanism. The sustainable agricultural system which is near to the Egyptian paradigm is diverse, complex, and resource-poor system. It should be clear that sustainable agriculture will be reached in Egypt by achieving the following conditions and recommendations:

1. Understanding that sustainable agriculture is achievable.
2. Policy makers should deal with sustainability as an integrated system, sustainable agriculture can't be reached by finding solutions to the challenges of the Egyptian agriculture sector one by one.
3. Science and research can't support sustainability if they are far from people. Farmers have to be involved in the research system by providing information, making analysis, introducing solutions, and implementation.
4. Enabling external institutions and applying resource-conserving technologies should be integrated with local groups and institutions as a condition for sustainable agriculture. All the actors should work together in the agricultural system.
5. Egypt is poor in natural resources; in addition farmers have not enough financial power to use external outputs. We should build our strategies to reach the resource-poor sustainable agriculture system. Embracing tries to reach industrialized or Green Revolution systems as a road to obtain higher production, and benefits will have negative effects on the Egyptian agriculture system as a whole.
6. Any plans or solutions should be technically, ecologically, economically, and socially accepted according to local conditions.
7. Policies should be supportive to any sustainable agriculture strategy; the fact here is sustainable agriculture is not just related to plans or resources. It is about the supportive policies which will serve all of this [50].

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Part II
Overview of Egyptian Sustainable Agriculture

Deficit Irrigation Management as Strategy Under Conditions of Water Scarcity; Potential Application in North Sinai, Egypt

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Contents

Abstract Water plays an essential role in yield productivity; however, in the near future it seems that many Arabian and African countries will suffer from water scarcity periods. Egypt, as one of the Arabian and African countries, reflects this

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phenomenon as a result of increases in population, economic activities, living standards, and cultivated land, as implemented by the plans of successive Egyptian governments. Total water withdrawal between 2010 and 2015 was 68.3 km^3/year, which was distributed among agricultural, municipal, and industrial sectors. The agricultural sector is considered the main consumer as it is the core of the Egyptian economy; the agricultural sector consumed approximately 59 km^3/year for irrigation purposes and other agricultural activities. With double cropping or two crops per year, intensive agriculture has doubled the water demand. In addition, loss of water by evapotranspiration from the cultivated lands is estimated to be 3 km^3/year. In order to identify both the effects of reduced water supply on yield characteristics and water use efficiency (WUE) in newly reclaimed lands, we applied our experiments in North Sinai, which is one of the strategic lands planned for reclamation by the Egyptian government.

Three irrigation treatments were performed: 3,600m^3/ha (W1), 6,000 m^3/ha (W2), and 7,200 m^3/ha (W3; normal and recommended irrigation dose) with water from the El-Salam canal, using faba bean (Vicia faba L.) as the dominant crop in this region. The obtained results revealed that a relative decrease in soil salinity, compared with the initial soil salinity, occurred in parallel with increasing water supply regimes, by an average of 33.0%, 37.4%, and 47.6% for W1, W2, and W3 respectively. The WUE showed another phenomenon. Using the W1 water regime with faba beans under saline soil situations saved approximately 50% of the added water and showed a higher WUE of 2.36 kg/m^3 compared with W2 and W3, which resulted in WUE values of 1.75 kg/m^3 and 1.39 kg/m^3, respectively. Also, we produced a simulated yield model of the obtained yield with the field characteristics (R^2 of 0.98), and the model performance indicated a small root mean square error, of 0.12.

Keywords Soil nutrients, Soil salinity, Water stress, Water use efficiency, Yield model

1 Introduction

Increasing competition for water resources among the agriculture sector and the domestic consumption sectors, such as the municipal and industrial sectors, will require new irrigation strategies to allow water saving, and these strategies could maintain efficient levels of production in semi-arid regions [1]. The National Sinai Development Plan that was implemented for the Sinai Peninsula (1997–2017) envisaged a national mega project for the development of 100,000 hectares (ha) of agricultural lands with the initiation of the El-Salam Canal [2]. This mega project planned to transfer part of the River Nile water eastwards (Damietta branch), aiming to divert it to Sinai for irrigating a strip of reclaimed land between the Suez Canal and North Sinai to create a new agriculture zone ending at Egypt's Eastern national border. With water scarcity being recognized, a national policy was implemented in the 1970s for a strategy of reusing agricultural drainage water for irrigation purposes.

For example, in the El-Salam canal in the eastern part of the Nile Delta, the Nile water is mixed with the agricultural drainage water at a ratio of 1:1 [3]. Total water withdrawal between 2010 and 2015 was 68.3 km^3/year, which was distributed among agricultural, municipal, and industrial sectors. The agricultural sector is considered the main consumer, as it is the core of the Egyptian economy; the agricultural sector consumed approximately 59 km^3/year for irrigation purposes and other agricultural activities. With double cropping or two crops per year, intensive agriculture has doubled the water demand. Also, the loss of water by evapotranspiration from the cultivated lands is estimated to be 3 km^3/year [4].

1.1 Food Security Under Conditions of Water Deficiency

Several definitions of food security have been used during the past two decades. The World Food Summit [5] defined it as “food security appears when all people have similar physical, economic, and social access to sufficient, safe food that meets their dietary needs and food preferences for healthy life”. However, owing to income disparities that could affect access to food, it is essential to distinguish between food security approaches at the national level and/or community level.

The Arabian countries are still suffering from a shortage of food commodities, especially cereals, in spite of efforts applied by their governments to overcome this critical issue. Another approach to food security refers to the availability of different commodities, such as cereals, carbohydrates, proteins, legumes, etc. Increasing cereal imports in Egypt and other Arabian countries has been attributed to many factors, such as the decline and loss of cereal yield as a result of land use changes, soil degradation, and increasing urbanization, with increased internal migration of people in rural areas to urban centers.

Egypt is suffering from shortages of many kinds of food, especially the most expensive commodities due water shortage. However, cereal production has increased from 5 billion Kg in 1961 to 23 billion Kg in 2008 [6]. Nevertheless, the production has never been sufficient to face the food demand for the increasing population. Thus, successive Egyptian governments have had to import cereals; the amounts ranged from 1.4 billion Kg in 1961 to 12.3 billion Kg in 2008 [7]. Egypt, as the largest wheat importer in the world, imported 10 billion Kg in 2010 [8]. In Egypt, food security is a result of different causes that can be attributed to international and/or domestic factors. Food prices for agricultural commodities have risen dramatically; these commodities are scarce in the global market as a result of the production of biofuels to replace oil, which consumes large areas worldwide that would have been used for cereal production [9]. Also, climate change has affected rainfall distribution in Egypt in many different areas, affecting the agrarian landscape. Increases in the cost of transportation have also had an important effect on food prices in Egypt. The increases in food prices overall can be attributed to the increase in total population, urbanization, and encroachment on arable land.

1.2 Arable Land Area

Egypt is an agrarian nation, and arable land areas have been a dominant issue since the beginning of the twentieth century. The total cultivated land area in 2008 was 3.5 Mha, and 90% of it was irrigated. The old land located in the Nile Delta covered 2.3 Mha, while reclaimed land located in the eastern and western portion of the Delta covered 1.0 Mha [5]. Irrigation systems used in Egypt comprise a mixture of conventional and modern techniques. The total area irrigated by flooding irrigation is 2.84 Mha, which comprises 89% of the total irrigated area. In the Nile delta, flooding irrigation (surface, and furrow) is used in 89% of the cultivated area along the Nile River. Sprinkler and drip irrigation, as modern irrigation systems, are also being used and practiced in greenhouse agriculture or reclaimed lands in large areas that have low water-holding capacity.

1.3 Water Resources

As Egypt, except for the northern region, is a semi-arid region, the rainfall amount is rather low. While intermittent torrents can occur in the north of the Sinai Peninsula and in Upper Egypt, this water flows into either streams or groundwater. Water resources can be distinguished as either conventional or non-conventional. Conventional resources confined to the Egyptian allocation are the withdrawal of fresh water from the Nile River, and the groundwater along the Nile River and its delta. Groundwater allocated on the northern and eastern coasts is identified as shallow groundwater, while that in the western and eastern deserts is identified as deep and non-renewable groundwater [10]. Non-conventional water resources consist of the reused water coming from treated wastewater, agricultural drainage, industrial drainage, and desalinized water that can be produced either from seawater or brackish water [11]. According to the treaty between the countries in the Nile Basin and Egypt, the water allocation from the Nile River for the Egyptian part is 56 km^3/year, which accounts for 98% of the total source of renewable fresh water and is for domestic use [10].

The majority of the Egyptian lands suffer from desertification and are distinguished as the western and eastern deserts. In these desert regions the renewable and non-renewable groundwater is considered to be the main source for agriculture and municipal use [12]. However, the river water sources are not accessible in the dominant delta regions. Thus, the local farmers have to use several methods to get fresh water, such as digging wells that mainly originate from the water percolation of the irrigation canals. Also, as a result of most Egyptian villages not having a potable water network, the residents drill small pumps manually to get fresh water for domestic and potable uses, and the renewable groundwater provides Egypt with 1.3 km^3/year [10].

Successive Egyptian governments have used several methods to identify and initiate other water resources, especially non-conventional resources. Reuse of agricultural drainage water has been considered for a long time. For example, the drainage water of El-Serw station was used for irrigation purposes in 1928, and a supporting station for recycling use was constructed in 1930. Shortly afterward, the government understood that the quality of the resultant agricultural drainage water from this station was close to that of the Nile water, and this drainage water resulting from the supporting station was pumped into the Nile River (Damietta branch). This strategy has been adopted since the 1970s [13], and policymakers set their strategies to be carried out through pumping of the agricultural drainage water of the main and branch drains and then mixing this water with fresh water in the Nile main and branch canals. In recent decades in Egypt, local farmers have directly used the agricultural drainage water from the drains closer to their farms for irrigation purposes, instead of depending on the irrigation canals, as many villages in the Delta drain their wastewater into the agricultural drains from which large areas are irrigated. In addition, treated wastewater is also used for irrigation. Reused wastewater resources, such as agricultural drainage and treated wastewater, represent 4.79 km^3/year of the water requirements in Egypt [12]. In this context, several researchers have reported that in coming decades more irrigated land will be drained, and hence more wastewater treatment stations should be constructed in the Delta region, a region that reflects the increasing use of treated wastewater, with an increase of 11 km^3/year projected to occur by 2017 [12].

1.4 Soil Water Management

In the modern world, the economic approach to water is regarded as *Blue Gold*. The agricultural sector is considered to be the most significant water consumer, consuming approximately 70% of the world's total water, and this will increase in the future [14]. In recent decades, scientists have identified the water consumed in agricultural production as *virtual water* [15, 16]. *Virtual water* is characterized by three components: blue, green, and gray. Blue water refers to surface and groundwater, while green water refers to rainfall water and/or soil water. Water that percolates into soil contaminated by chemical compounds (e.g., fertilizers and pesticides) or water that is disposed of as municipal effluent, is called gray water [17]. The stakeholders are using recent technologies to manage the processes of converting blue water and/or gray water to green water for irrigation to increase water use efficiency (WUE). Thus, the use of modern irrigation systems and irrigation at night and/or even in the early morning could result in increasing the WUE and decreasing water losses by evaporation.

Soil hydrological and physical properties strongly affect the hydrological balance, and knowledge and management of these properties can result in the preservation and management of green water that is lost by leaching and evaporation in arid regions. This strategy is also applied to enhance the soil water-holding capacity

(SWHC) and reduce losses by evaporation. Soil texture is strongly correlated with the SWHC, so that the finer the soil texture, the higher is the SWHC [18].

1.5 Deficit Irrigation

Deficit irrigation (DI) is a recent irrigation technique that is applied during various growth stages of drought-sensitive plants if irrigation is limited and/or rainfall provides a minimum supply of the required water. Thus, DI is an important approach to increase WUE [19, 20]. In arid regions, as there is limited water, plants reflect drought tolerance during the phenological stages of growth, especially in the vegetative stages and particularly during the late ripening period. While this limited water supply inevitably has effects on plant drought stress and production loss, DI enhances irrigation water productivity and WUE, which is the primary limiting factor in plant growth [21]. Furthermore, one of the aims of DI is stabilizing yields and obtaining relevant crop water productivity, rather than obtaining maximum yields [22]. The approach of increasing food production and food safety with less water, in countries with limited water, associated with the available land resources, has become a leading challenge in recent decades, owing to severe water scarcity [20]. Thus, new approaches to enhance irrigation scheduling should be considered to achieve optimum water supply for yield productivity, while maintaining the soil water content close to the field capacity to increase WUE. Also, the decision on irrigation scheduling is made by the local stakeholders to maximize profit, to determine when and how water should be applied to a field. This irrigation scenario aims to increase irrigation efficiency by supplying the soil with the precise amount of water needed to bring the soil water to the relevant level, and at the same time, save energy and water.

Deficit irrigation comprises irrigating into the root zone with less water than that required for evapotranspiration [22]. The best combination of acceptable yield reduction and water use that results from water-saving strategies is vital for different crops [21]. For areas with long summer droughts (North Sinai, Egypt) and water scarcity, DI is highly recommended for the overcoming of severe yield reductions and securing low yield levels [23]. A preliminary study in North Sinai [20, 24] showed that the influence of DI on crop yield and physiology led to significant variations in crop productivity, physiology, and quality. In addition, the awareness of WUE concepts and the significant relationship between soil water deficiency and crop productivity supported policymakers and farmers in optimizing water management and irrigation water supply [25]. The results obtained using DI in arid and/or semi-arid regions succeeded in increasing the total water-holding capacity of soils by 75% and contributed to increases in faba bean plant height, number of pods/plant, 100-seed weight, seed yield/plant, numbers of plant branches, and seed yield/ha [26]. Another study [27] found that adding 50% of the water requirements also significantly increased the crop productivity of the faba bean. Otherwise, irrigation using half of the required water supply during vegetative growth showed greater increases in yield productivity than those noted with the full irrigation. In addition, Marschner [28] mentioned that decreasing the water availability in soils affected the soil nutrient diffusion rate and concentration of the soil solution, revealing an apparent decrease in plant nutrient uptake. Soil salinity, the other major phenomenon in the arid and semi-arid environment, is considered a major and severe environmental threat for crop production in many parts of the world, especially those which depend on irrigated agriculture and those associated with high water tables and poor drainage. Annually, 2% of the arable land all over the world becomes unsuitable for cultivation as a result of the salinity effect and waterlogging [5]. As a result, plant growth can be inhibited for several reasons; the effect of salt types and their quantity in the soil solution, and subsequently the plant's ability to take up nutrients and water, lead to reduced plant growth rates. This action can occur owing to the mechanism of osmotic pressure and/or the water deficit effect of salinity [20, 29]. Also, when salts enter the plant in excessive amounts during the transpiration stream process, the cells involved in transpiration in the leaves would be injured. This would lead to deterioration in the phenology and photosynthesis processes and a reduction in the plant growth rate [25, 29].

2 Egypt Case Study

2.1 Experimental Site

The objectives for this case study were to determine the effect of different water supply scenarios on soil nutrients and their distribution through two growth seasons and different months under high saline soil conditions in North Sinai, Egypt, in a semi-arid Mediterranean climate. This study also aimed to identify and determine the WUE under that climatic condition, and the yield productivity of the faba bean (*Vicia faba L.*) in this environment.

Field experiments were carried out during two successive winter seasons, 2012/2013 and 2013/2014, at Gellbana village in Sahl El-Tina (Fig. 1), North Sinai Governorate, at an experimental farm (31° 00′ N latitude and 32° 30′ E longitude). The region has a continental climatic condition with a wet winter and hot dry summer. The lowest temperatures occur in January and February (22 and 20°C), while the maximum amount of rainfall is 12.7 mm/month, in February. The highest humidity is 70%, in January [3], and the soil is characterized as a sandy loam with pH 8.18, average salinity (EC) 10.23 dSm^{-1}, $CaCO_3$ 6.90 g kg^{-1}, and organic matter 0.44 g kg^{-1} [20].

The soil is irrigated from the El-Salam canal, with an average salinity (EC) of 1.38–1.47 dSm^{-1}. Representative water samples in the study area were collected during the winter season (October, December, January, and March) for two successive years. The irrigation water was analyzed (Table 1) for cations and anions according to the methods outlined by Cottenie et al. [30].

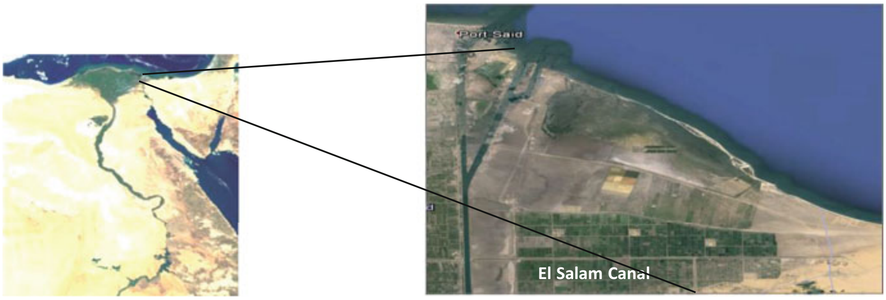

Fig. 1 Location of experimental area at Gellbana village in Sahl El-Tina, North Sinai. After Abu-hashim and Shaban [20]

2.2 Experimental Design

The experiment was prepared using a randomized complete block design with three replications. Faba bean (*Vicia faba L., cultivar* Sakha-3) was employed in this region as our test crop through the two seasons of the experiment. Three irrigation levels were implemented: W1 with 3,600 m^3/ha, W2 with 6,000 m^3/ha, and W3 with 7,200 m^3/ha (normal irrigation used by the local farmers). The irrigation supply was by surface flow through pipelines that had meter gauges to control the amount of added water. To overcome the soil salinity hazards that could affect the plant sowing processes, the experimental soils were irrigated for 4 h on the first day of plant sowing. On the second day of plant sowing, the soil was irrigated for 7 h, and then every 10 days. The sowing dates in the three regions were November 25th and 28th for the first and second seasons, respectively. The faba bean seeds were planted in hills on one side of a ridge, with 20 cm between the hills, at a rate of three seeds per hill. By thinning the seedlings at 35 days after sowing, one plant per hill was maintained. Each experimental plot consisted of six ridges; 5 m in width and 10 m in length, 60 cm apart.

The first part of the fertilization regime consisted of calcium superphosphate (15.5% P_2O_5) at 360 kg/ha applied before planting. Then potassium sulfate (48% K_2SO_4) was applied at 120 kg/ha in two equal doses at 21 and 45 days after sowing. The basic application of nitrogen, added as urea (46% N), was done at a rate of 48 kg/ha, on the same dates. Harvesting of the plants was performed at maturing (mid-May) in both seasons. To estimate plant height (cm), 100-seed weight (g), seed yield (t/ha), seed weight (g seed/plant), aboveground biomass (t/ha), and harvest index (%), samples of ten guarded plants from each experimental plot were taken randomly. The harvest index was calculated by dividing the seed yield by the aboveground biomass, and the WUE was determined according to Bos [31], depending on the aboveground biomass, using the following equation:

Table 1 Water characteristics of the El-Salam Canal, which was used for irrigation in two seasons (2012/2013 and 2013/2014)

	EC (dSm^{-1})		pH		SAR		Adj SAR		RSC		ESP	
Parameters	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
October	1.20	1.30	8.00	7.90	3.82	3.01	6.11	5.71	−4.11	−5.20	4.41	3.21
December	1.34	1.37	7.98	8.00	3.62	2.85	5.97	5.41	−4.21	−5.37	4.12	2.97
January	1.40	1.44	7.95	7.98	3.58	2.74	6.08	5.21	−4.24	−5.49	4.06	2.81
March	1.37	1.41	7.95	7.97	3.48	2.80	5.52	5.31	−4.39	−5.42	3.87	2.89

From Abu-hashim and Shaban [20]

1st first season (2012/2013), *2nd* second season (2013/2014), *SAR* sodium adsorption ratio, *Adj SAR* adjusted sodium adsorption ratio, *RSC* residual sodium carbonates, *ESP* exchangeable sodium percentage, *EC* salinity

WUE = seasonal biomass as dry matter/kg divided by seasonal water in ET.
ET = equivalent dry land or rain-fed plot.

2.3 Statistical Analysis

Data for yield and quality traits were statistically analyzed by one-way analysis of variance (ANOVA), using CoStat version 6.003 (CoHort Software), and the differences between means were evaluated for significance using the least significant differences (LSD) test, according to Sendecor and Cochran [32].

To compare the obtained results for yield productivity with the estimated results for yield from the measured field characteristics (simulated yield model), the root mean square error (RMSE) was applied as a criterion to reveal the goodness of the simulation.

This is expressed as:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} \left(\mathrm{Observed}_i - \mathrm{Simulated}\right)^2}{n}}$$

where n is the total number of observations.

3 Results

3.1 Irrigation Water Characteristics

As the irrigation water of the El-Salam canal is a mixture of Nile water and agricultural drainage, the concentrations of cations and anions (except for Na^+) showed an increasing order from the first season of the experiment to the second one and from October to January (Fig. 2). Also, the results showed that excessive solutes in irrigation water are a widespread problem in semi-arid regions [33].

For the solute distributions according to months, the concentrations followed an ascending order for the cations; Ca^{2+}, Mg^{2+}, and K^+. However, the Na^+ concentrations displayed a descending order, where Na^+ decreased from 6.20 to 5.79 meq/l and decreased from 5.57 to 5.26 meq/l in the first and the second seasons, respectively.

For semi-arid regions, the Food and Agriculture Organization (FAO) [5] used the sodium adsorption ratio (SAR) as an efficient parameter to estimate the suitability of irrigation water, and they documented a range of 0–15 meq/l. The obtained results revealed that, for our case study in North Sinai, El-Salam canal water was already within such permissible SAR limits (Table 1).

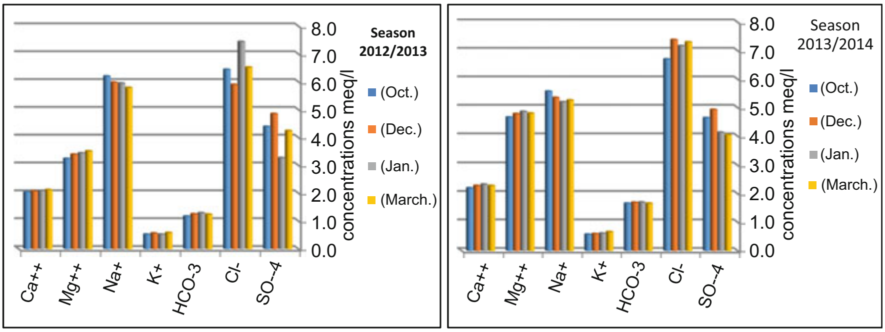

Fig. 2 Chemical parameters (meq/l) of the irrigation water of the El-Salam canal during representative months for the two successive winter seasons 2012/2013 and 2013/2014. After Abu-hashim and Shaban [20]

As the SAR is related to the sodium concentration in the irrigated water (in this case, the El-Salam Canal), the SAR ratio was affected by the seasonal changes during the investigated months. This phenomenon was also noted for other parameters investigated, such as the adjusted SAR, Soluble Sodium Percentage (SSP), and the exchangeable sodium percentage.

The obtained results for water salinity and its distribution during the two seasons and its changes during the investigated months revealed that the EC (dSm^{-1}) of the El-Salam canal was higher in the months of the second season than in the first season (Table 2). In addition, the salinity concentration revealed higher values in January, compared with the other months, in both seasons. This phenomenon could be a result of the Egyptian water irrigation strategy called deadline winter blockage, which occurs in January, in which the streams are closed and the water supply that can reach the El-Salam canal would be reduced. This strategy is usually carried out in winter every year, especially in the month of January, and it occurs in parallell with the impact of temperature in this semi-arid region, resulting in increased concentrations of the different solutes and so increasing the salinity concentration.

3.2 Canal Nutrient Characteristics

The nutrient concentrations varied with the investigated months and from one season to the other, and the concentrations followed an ascending order among the months (Fig. 3). For the first and second seasons, respectively, the NO_3-N concentration increased from 9.23 and 12.17 mg/l in October to 18.22 and 17.84 mg/l in March. Otherwise, for the first and second seasons, respectively, NH_4-N increased from 5.40 and 7.40 mg/l in October to 9.02 and 8.77 mg/l in March. The same phenomenon

Table 2 Effect of different irrigation supply regimes combined with the seasons' and the months' impacts on soil salinity (dSm^{-1}) and nutrient composition ($mg\ kg^{-1}$)

Treatment	EC	N	P	K	Fe	Mn	Zn
S1 + M1 + W1	8.93	62.0	4.69	180.0	2.03	3.58	0.83
S1 + M1 + W2	7.95	64.1	4.75	193.0	1.98	3.66	0.90
S1 + M1 + W3	6.52	69.8	4.89	198.0	1.96	3.70	0.92
S1 + M2 + W1	7.30	65.0	4.77	184.0	2.12	3.63	0.85
S1 + M2 + W2	6.73	67.3	4.82	197.0	2.03	3.69	0.93
S1 + M2 + W3	5.23	69.5	4.93	202.0	2.05	3.73	0.95
S1 + M3 + W1	6.95	69.7	4.80	193.0	2.06	3.75	0.88
S1 + M3 + W2	6.32	72.2	4.86	206.0	2.06	3.71	0.95
S1 + M3 + W3	5.12	74.6	4.97	208.0	2.09	3.76	0.99
S1 + M4 + W1	6.46	74.0	4.83	198.0	2.10	3.73	0.93
S1 + M4 + W2	6.20	75.6	4.88	208.0	2.08	3.74	0.98
S1 + M4 + W3	5.03	76.3	4.96	212.0	2.10	3.78	0.98
S2 + M1 + W1	7.20	60.0	4.85	195.0	2.00	3.60	0.88
S2 + M1 + W2	6.85	65.9	4.88	201.0	2.04	3.68	0.93
S2 + M1 + W3	6.10	68.3	4.92	208.0	2.06	3.73	0.95
S2 + M2 + W1	6.88	64.0	4.90	198.0	2.04	3.64	0.93
S2 + M2 + W2	5.96	68.6	4.93	206.0	2.08	3.71	0.96
S2 + M2 + W3	5.09	71.6	4.95	213.0	2.09	3.75	0.98
S2 + M3 + W1	6.20	75.0	5.00	204.0	2.08	3.67	0.96
S2 + M3 + W2	5.83	69.3	4.98	208.7	2.10	3.75	0.98
S2 + M3 + W3	4.92	75.1	4.99	216.0	2.13	3.77	1.02
S2 + M4 + W1	5.79	70.0	5.02	207.0	2.11	3.74	0.98
S2 + M4 + W2	5.40	73.1	4.91	212.0	2.13	3.78	0.99
S2 + M4 + W3	4.88	77.9	5.01	218.0	2.16	3.81	1.04
$LSD_{0.05}$	0.02	0.17	ns	1.48	0.03	0.04	ns

From Abu-hashim and Shaban [20]
LSD least significant difference, *ns* not significant, *S1* and *S2* first and second seasons, *M1* October, *M2* December, *M3* January, *M4* March, *W1* irrigation with 3,600 m^3/ha, *W2* irrigation with 6,000 m^3/ha, *W3* normal irrigation with 7,200 m^3/ha

was noted for the phosphorus and potassium concentrations for the two successive seasons and within the months [34]. However, for the investigated heavy metals (Fig. 3), the highest heavy metal concentrations were noted for Mn (1.59–1.80 mg/l) and then Zn (1.05–1.15 mg/l), while the lowest was Fe (0.93–1.05 mg/l). A reduced concentration of ammonium nitrate in surface water was not apparent in the investigated samples. Leaching and surface runoff from agricultural practices, and water contamination with animal and human waste in the streams can lead to high ammonium nitrate values [35, 36]. Nevertheless, the concentrations of ammonium (5.40–9.02 mg/l) and nitrate (9.23–18.22 mg/l) found in this study could be within permissible limits [35]. Industrial residues are one of the most significant sources of heavy metals that can pollute the aquatic environment, as heavy metals are not

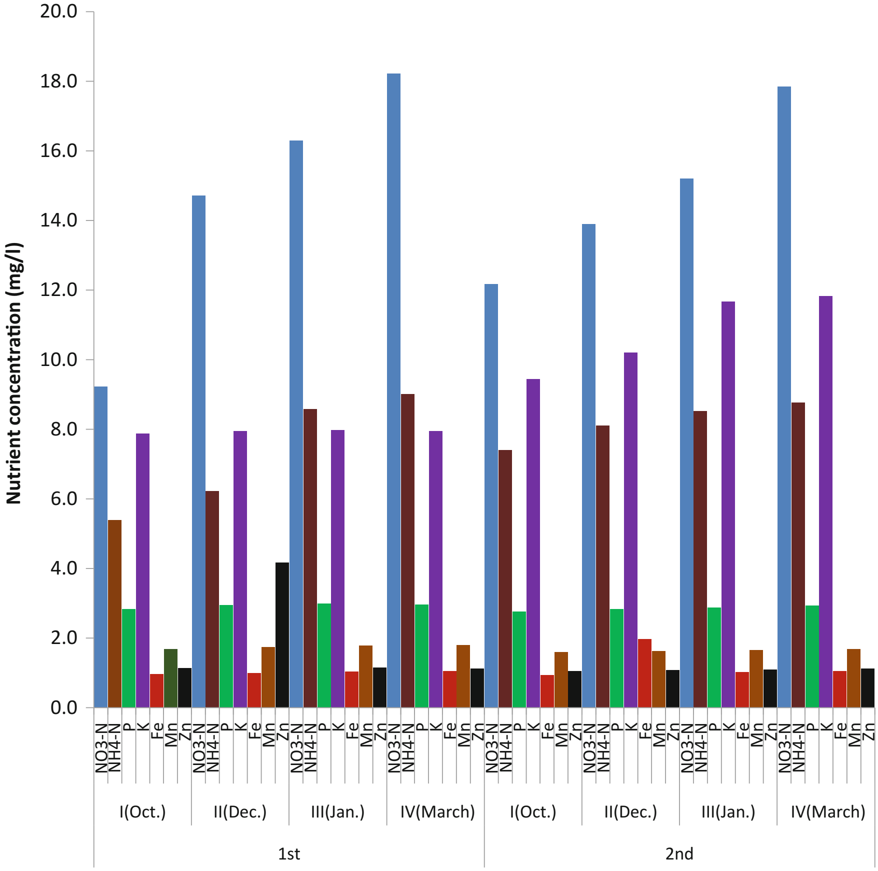

Fig. 3 Nutrient concentrations (mg l^{-1}) in the El-Salam Canal, which was used for irrigation in two seasons (2012/2013 and 2013/2014)

environmentally degradable. Their discharge into rivers and streams can cause deleterious health effects [37, 38]. Our chemical analysis of the El-Salam canal sediment revealed that the concentrations of Fe, Zn, and Mn met the allowable levels for irrigation [5]. The literature has revealed that for the Damietta branch, whence the El-Salam canal receives its main water resources [39], sediment analysis showed a high concentration of heavy metals, of the order of Fe > Mn > Cu > Zn > Pb > Cd. With the obtained field survey and the results of chemical analysis of these pollutants, it appears that the El-Salam canal carries wastewater with high potential levels of agrochemical residues and other terrestrial materials from the cultivated Nile Delta region to the eastern part of Sinai.

3.3 Water Stress Impact on Soil Salinity

In our study, to identify and estimate the impact of the irrigation supply regimes on soil salinity and soil nutrients for the two seasons, samples were collected from the soil surface layer (0–30 cm) 4 days after irrigation. The soil salinity in the investigated seasons and months indicated significant differences in the water stress (see Table 2). The initial soil salinity for Sahl El-Tina was 10.23 dSm^{-1}, and we noted that there was a relative decrease in soil salinity along with the increase in water supply. Compared with the initial soil salinity, the data for all field treatments in the different months and seasons revealed that, for the standard irrigation supply (W3), soil salinity was reduced in the first and second seasons by 46.5% and 48.7%, respectively.

3.4 Soil Nutrient Availability

Compared with the initial soil nutrient values in the study area, the soil nutrients were increased with increasing water amounts (see Table 3). The mean phosphorus value was increased by 16.5% using the W3 water regime compared with water regimes W1 and W2, with increases of 14.3% and 14.7%, respectively, compared with the initial soil phosphorus value (4.25 mg kg^{-1}). The heavy metals, i.e., Zn, Fe, and Mn, revealed a descending order with increasing water stress (see Table 4). The reduction of nitrogen and phosphorus availability with water stress (from W3 to W1 treatments) was attributed to the decrease in nutrient diffusive flux during the water stress [40].

Nutrient availability was enhanced by increasing the soil water; this approach agreed with the potassium availability, which decreased with increasing water stress (Table 3). Of note, Zeng and Brown [41] reported increased potassium flux and

Table 3 Soil nutrient availability, compared with the initial soil concentration, and its relative impact under the influence of different levels of deficit irrigation

Relative impact	Nutrient	Initial soil	Season					
			First season			Second season		
			W1	W2	W3	W1	W2	W3
Relative increase	N (mg kg^{-1})	45.00	0.50	0.55	0.61	0.50	0.54	0.63
	P (mg kg^{-1})	4.25	0.12	0.14	0.16	0.16	0.16	0.17
	K (mg kg^{-1})	178.0	0.06	0.13	0.15	0.13	0.16	0.20
	Zn (mg kg^{-1})	0.81	0.08	0.16	0.21	0.16	0.19	0.27
	Fe (mg kg^{-1})	1.39	0.49	0.47	0.48	0.48	0.50	0.52
	Mn (mg kg^{-1})	3.43	0.07	0.08	0.09	0.07	0.09	0.10

From Abu-hashim and Shaban [20]
W1 irrigation with 3,600 m^3/ha, *W2* irrigation with 6,000 m^3/ha, *W3* Normal irrigation with 7,200 m^3/ha, *1st* first season (2012/2013), *2nd* second season (2013/2014)

Table 4 Correlation analysis of the measured field parameters and the obtained yield in two seasons, 2012/2013 and 2013/2014

	Yield	Irrigation treatment	EC	N	P	K	Fe	Mn	Zn
Yield	1	0.885[a]	−0.579	0.714	0.348	0.703	0.416	0.768	0.703
Irrigation treatment		1	−0.825[a]	0.930[b]	0.529	0.787	0.507	0.939[b]	0.745
EC			1	−0.830[a]	−0.891[a]	−0.919[b]	−0.754	−0.926[b]	−0.877[a]
N				1	0.517	0.758	0.550	0.930[b]	0.702
P					1	0.877[a]	0.777	0.696	0.867[a]
K						1	0.866[a]	0.902[a]	0.995[b]
Fe							1	0.757	0.872[a]
Mn								1	0.863[a]
Zn									1

From Abu-hashim and Shaban [20]
[a]Correlation is significant at the 0.05 level (two-tailed)
[b]Correlation is significant at the 0.01 level (two-tailed)

increased soil efficiency with increases in soil moisture. Hagen and Tuker [42], in 1982, demonstrated that decreases in Mn, Fe, and Zn availability with soil water stress (Table 3) could be attributed to the high soil pH in soils that contain high concentrations of calcium carbonate; hence these nutrients would not be available to the root system.

3.5 Yield Characteristics

The correlation analysis results for the measured field experimental parameters and the obtained crop yield in both seasons (2012/2013 and 2013/2014), showed that the relationship of the crop yield and the water regime had a positive trend as a result of increasing the water supply (Table 4). On the other hand, a negative trend in response to the water supply regime and the soil salinity was noted. The same significant negative trend was also noted between the soil salinity and soil nutrients (N, P, K, Mn, and Zn).

The water regimes used in this experiment (W1, W2, and W3) showed differences in the biomass yield (Mg/ha) with drought stress (see Table 5). These results agree with those of DeCosta et al. [43], who reported that yield component analysis of faba bean had a positive yield response for the water supply regime, as well as for increases in total biomass.

Our field results showed that with the W2 water regime the biomass yield was more efficient than that with the W3 water regime (normal irrigation) and that with the W1 regime (Table 5). These results are consistent with the results of Hirich et al. [27], who reported that the DI strategy, using half of the required water, during vegetative growth revealed higher yield productivity than that seen with the full irrigation amount. We found that the WUE showed another phenomenon. Namely, using the W1 water regime under saline soil conditions in an arid region saved 50% of the required water amount and showed a higher WUE, at 2.36 kg/m^3, than using the W2 and W3 regimes, which led to WUE values of 1.75 kg/m^3 and 1.39 kg/m^3, respectively for the first and second seasons (see Table 5). These results are in agreement with the findings of Al-Suhaibani [44], Link et al. [45], and Alireze and Farshad [46].

3.6 Evaluation of Yield Simulation Model

The obtained field measurements were calculated by using the solver program of *Microsoft Office Excel 2010* to model the field data and find the optimal estimated value for the yield under the measured field parameters. The results revealed:

Table 5 Impact of water stress on yield and yield compound and water use efficiency for the two seasons 2012/2013 and 2013/2014

	Weight straw (g)/plant		Weight 100-seed (g)		Weight seed (Mg/ha)		Biomass yield (Mg/ha)		Harvest index (%)		WUE (kg/m^3)	
Parameter	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
W1	12.84	14.19	50.67	56.33	2.84	2.87	8.39	8.56	33.82	33.52	2.33	2.38
W2	20.67	18.14	67.00	76.33	3.01	3.06	10.37	10.60	29.06	28.87	1.73	1.77
W3	16.35	23.07	62.00	67.33	2.86	2.93	9.87	10.04	29.00	20.14	1.37	1.40

From Abu-hashim and Shaban [20]

WUE water use efficiency, *W1* irrigation with 3,600 m^3/ha, *W2* irrigation with 6,000 m^3/ha, *W3* normal irrigation with 7,200 m^3/ha, *1st* first season (2012/2013), *2nd* second season (2013/2014)

$$\text{Simulated yield} = 0.001\ \text{WSA} + 0.856\ \text{EC} - 0.296\ \text{N} + 0.808\ \text{P} + 0.042\ \text{K} + 0.944\ \text{Fe} + 0.865\ \text{Mn} + 1.007\ \text{Zn} + 0.961$$

where *WSA* is the water supply amount, *EC* is soil salinity (dSm^{-1}), and *N, P, K, Fe, Mn,* and *Zn* are the measured nutrients expressed as mg kg^{-1}. To compare the obtained yield productivity with the estimated yield of the measured data (simulated yield model), the RMSE was applied as a criterion to reveal the goodness of the simulation. The simulated yield model correlated well with the obtained yield results of the field measurements, with an R^2 of 0.98, and the good performance of this comparison can also be indicated by its small RMSE, of 0.115.

4 Conclusion and Recommendations

Most of the countries in the Middle East and North Africa are located in arid regions with high temperatures and low rainfall. In Egypt, the finite conventional water resources in the arable lands are decreasing with the continuous increase in population, and this is considered to be the principal cause of water scarcity in the country. The use of non-conventional water resources (i.e., treated industrial and wastewater drainage, reused agricultural drainage water, and desalinated water) is now one of the main approaches being explored to increase water resources. In addition, green water can be obtained by enhancing soil water conservation, such as by following conservation tillage methods, increasing soil organic matter, and covering soil surfaces with plant residues. Also, surface irrigation, which is employed extensively in the Egyptian arable lands, can be compensated by modern irrigation systems (sprinkler and drip, etc.).

Our case study of Egyptian saline soils with a shortage of water that does not lead to reasonable yields showed that efficient irrigation is required in the growing season. In the El-Salam canal water, the main source of irrigation in our study area, the results of our chemical analysis agreed with FAO permissible levels. In addition, the level of soil nutrients revealed a descending order with increasing water stress. We conclude that, although the soil salinity decreased by 47.6% with the normal water irrigation supply (W3), compared with the W1 and W2 regimes, the use of the W1 regime saved 50% of the supplied water and resulted in a higher WUE, at 2.36 kg/m^3, than using the W2 and W3 regimes, with WUE values of 1.75 kg/m^3 and 1.39 kg/m^3, respectively. Thus, we conclude that, with the water scarcity problem that has faced Egyptian stakeholders in recent decades and with the salinity problem that has appeared in several places, such as North Sinai, DI can save water and lead to acceptable crop productivity. For different crops in areas of long summer droughts, such as North Sinai, the best combination of an acceptable yield reduction and water use strategy resulting from water saving is important under conditions of water scarcity. Thus, DI is highly recommended for the overcoming of severe yield reductions and for securing the low yield level (Fig. 4).

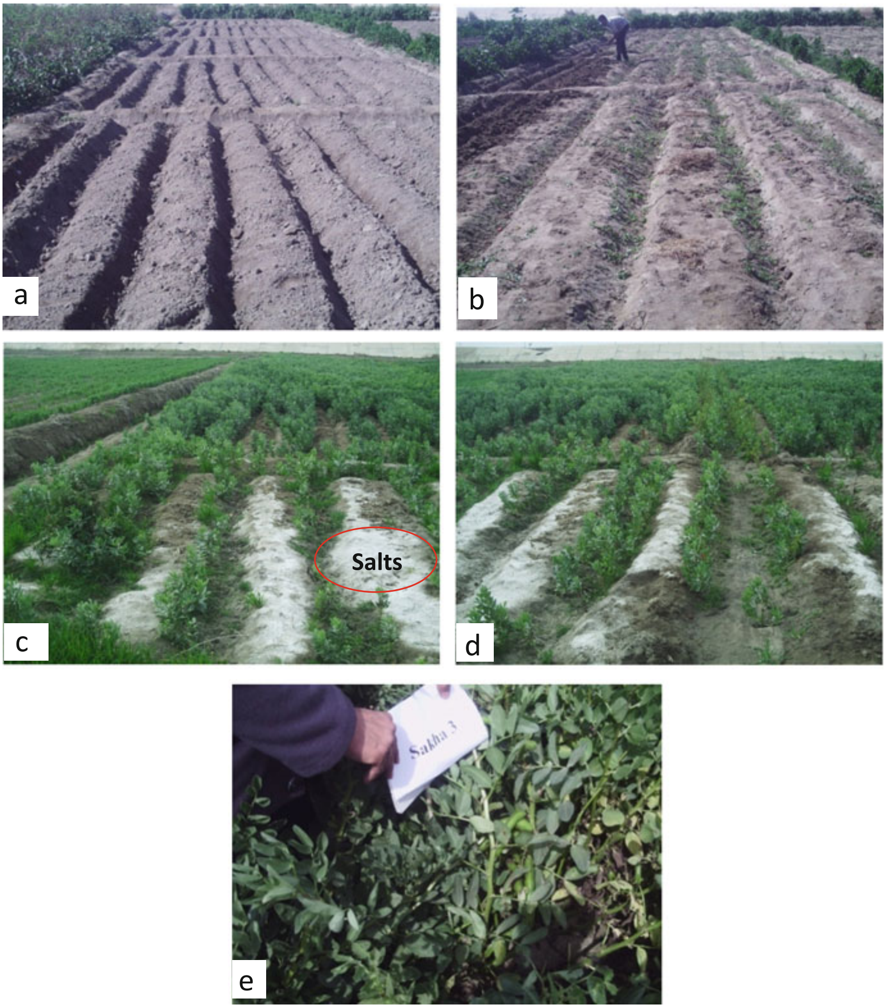

Fig. 4 (**a**–**e**) Growth of faba bean plants under high-salinity conditions. (**a**) Seedbed preparation before planting. (**b**) Sowing and treatment process. (**c**) Irrigation water at rate of 3,600m^3/ha, (**d**) irrigation water at rate of 6,000 m^3/ha, (**e**) irrigation water at rate of 7,200 m^3/ha per plot unit and planting of faba bean cultivar Sakha-3

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Soil Toxicology: Potential Approach on the Egyptian Agro-Environment

Eman Hashem Radwan

Contents

Abstract Possibly poisonous components represent a risk to human well-being as they can enter the human body by means of ingestion of the contaminated soil, residue. While most metals are fundamental supplements, some fill in as mechanical and ecological dangers if the homeostatic system that keeps up them inside physiological points of confinement is unequal. Others fill no organic need, while still others can possibly deliver ecological infections. Toxicology is more than art of toxic substances. One could characterize a toxic substance as any specialist that is fit for delivering an injurious reaction in an organic framework or equipped for pulverizing life or genuine harming capacities. Or maybe the toxicologist has a commitment to make the recognizable proof of danger characterized as the likelihood that damage will come about because of a compound under particular conditions and to foundation of breaking points of security characterized as the reasonable assurance that damage will not come about because of utilization of a substance under indicated states of

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value and way of utilization. Presentation to direct groupings of heavy metals can create an assortment of unmistakable impacts without really executing a living being. Assessment of toxicological impacts depends on perceptions of behavioral impacts, surviving, and tissue collection of metals. Heavy metal concentrations posture serious well-being risks and natural worries all through soil-evolved way of life exchange. By portrayal, the small microflora shown in the polluted soil in examination with the unpolluted soil and by segregating and describing particular microorganisms fit for debasing the contamination. The bacteria including *cyanobacteria* and *actinomycetes* are wide spreading in normal and with debase different mixes.

Keywords Agriculture, Biochar, Bioremediation, Food, Health, Soil, Toxicology

1 The Definition of Soil

The meaning of the soil was that it is a medium for plant development [1]. The soil can likewise be specified as a mantle of free weathering rock [2]. A third perspective of the soil is that it is the energized skin of the subaerial part of the earth's crust [3]. Chesworth [4] viewed soils as systems spontaneously moving toward a state of equilibrium. Hugget [5] viewed soil as storing, transforming, and transmitting whose inputs are material and energy. Daniels and Hammer, and Dmitriev [6, 7] presented a detailed analysis of the existing definitions of soil. Targulian and Skolova [8] described the soil as a reactor, memory, and regulator of biosphere interactions. Dabrovolskii et al. [9] considered the soil as a component of the biosphere with ecological functions. Nikitin [10] considered the soil as an abiotic system with numerous biospheric functions and emphasized that the soil acts as a habitat, accumulator, for terrestrial organisms. According to the soil taxonomy, the soil is a natural body composed of solids, liquids, and gases that occurs on land surface, occupies space, and is characterized by horizons or layers.

The poly pedon was perceived as a soil individual that contains bordering pedons, all of which have attributes existing in the characterized furthest reaches of a solitary soil arrangement or soil mapping unit. The weathering profile, the geologic homologue of the soil profile, is characterized as a vertical area that amplifies descending through the zones influenced by sub-aerial weathering to the unweathered zones of unconsolidated or merged geologic material [11, 12]. A catena was perceived as a seepage grouping of soils [13]. Brikeland [14] broke down different ways to deal with the part of time in soil improvement and diverse plans of soil arrangement that incorporated the time elements.

Targulian and Skolova [15] developed the idea of the soil as a moment which was represented by labile short-term soil forming processes. Simson [16] said that soil horizons form from two overlapping steps; the accumulation of parent materials and the differentiation of horizons in the profile. Crompton [17] suggested that the soil formation represented the balance between release of elements from weathering and loss of elements due to leaching. Bockheim and Gennadiyev [18] incorporated methodologies of various examiners and recognized 17 rudimentary soil-shaping procedures that could be connected to soil taxa and indicative skyline [19]. The soil is a multivariable common body that progresses at various rates into assorted mixes of the characterizing traits [20]. The meanings of soil horizons depended on the substantive soil properties managed by soil-forming processes [21]. Cline outlined the essential standards of soil characterization that were the establishment of worldwide soil arrangements, for example, [22]. Soils are ordered on the premise of analytic surface horizons, subsurface horizons, and different attributes.

2 Key Concepts Pertaining to Soil Classification

A zonal soil is with very much created attributes mirroring the impact of atmosphere and vegetation; an intra-zonal soil is all around grew yet has qualities reflecting nearby variables, for example, alleviation, parental material, age, and an a-zonal soil is one that needs all around created qualities.

Evolutionary frameworks recognize soils at larger amounts on the premise of the accumulation of hereditary soil horizons including the soil profile.

3 The Formation of Soil

Soil is formed after some time by the parental material (the compound and physical properties of the starting rock, alluvium/colluvium, or natural material), the atmosphere (over a significant time span, precipitation, and temperature, for instance), the fauna and greenery that have lived in it, the alleviation (the geomorphology and its impacts, for instance, on seepage), and time. The soil profile is a depiction of the vertical cross areas of the soil that normally happen in layers. These layers or horizons result from soil arrangement and extraordinarily portray the physicochemical nature of individual soils. It portrays three fundamental soil layers: topsoil, the highest layer containing most extreme biotic action; subsoil, found beneath the topsoil containing lessened measures of biotic movement; and the substratum, the base layer containing essentially unconsolidated material converged with hard rock.

The soil is an element of the transaction of atmosphere, life-forms, alleviation, and parent material, all working after some time. Parental material is the underlying mineral substance that structures a soil. The topographic alleviation or the incline affects the conveyance of soils on a scene. The atmosphere influences material translocation. The organic movement and the atmosphere are dynamic strengths in soil arrangement. The soil pedogenesis incorporates an assortment of creatures, plants, and microorganisms. The soil creates after some time. Soil development is a dynamic procedure, where a consistent state is gradually drawn nearer. The human action is needed that coordinates and contrasts between social orders and creates distinctive consequences for nature. The anthropogenic variable acts conditionally and autonomously of the other soil-shaping elements. They are autonomous in the event that where human impacts happen on timescales like regular soil arrangement, for example, water system.

Eluviation is the evacuation of material in suspension or arrangement basically from A and E horizons. Illuviation is the statement of these weathering items in B horizons. Huggett [23] detailed that soils speak to a harmony between soil development and dynamic denudation.

4 The Toxicity of Soil

It is essential that there are as of now numerous national and global endeavors in progress to create, enhance, and institutionalize strategies for evaluating soil quality, especially for use in arranging the potential perils of both soils and contaminant materials they may contain [24, 25]. Soil environment has been characterized as the investigation of characteristic variances in soil procedures and populaces of soil living beings. Soil environments are unimaginably perplexing with awesome heterogeneity in physical, compound, and natural attributes and are extensively affected by elements, for example, geography, geology, atmosphere, and anthropogenic exercises.

Bioavailability is characterized as the physicochemical get to that a toxicant has to the natural procedures of a living being [26]. The less the bioavailability of a toxicant, the less its harmful impact on a living being. Allen included that various physical and substance variables, including soil pH, natural matter, and synthetic type of the component in the earth (carbonate as well as sulfate), influence the potential for metal ionization and accessibility.

Soils are made out of remarkable blends of living and nonliving parts. The impact of contaminants on soil and soil life-forms mirrors the physical and chemical properties of the contaminants and the communication of the contaminants with the extraordinary segments and properties of each soil tried. The intrinsic limit and shifting capacity of each soil to adsorb, process, store, sequester, and amass contaminants can influence all parts of contaminant bioavailability and danger. Soil sorption of natural particles is controlled by the contaminant's properties, for example, molecular weight, ionic speciation, corrosive base properties, extremity, and nature of useful gatherings, and by soil properties, for example, natural matter substance, earth content, soil mineralogy and nature, pH, water content, mass thickness, cation trade limit, and percent base saturation. Whenever contaminants, even water-solvent contaminants, are unequivocally bound to natural materials, they may turn out to be successfully immobilized and in this manner moderately impervious to biodegradation. Exceptionally sobbed materials may, in any case, be vulnerable to extracellular enzymatic debasement. Sometimes, profoundly sobbed chemicals may likewise dislodge micronutrients, for example, inorganic supplement particles, from trade locales in the soil, conceivably influencing the well-being of natural segments.

5 Selection Tests for the Relevant Soils

Soil poisonous quality tests are for the most part intended to assess or distinguish the deadly or sub-deadly impacts of chemicals on living beings in soil biological systems. Bioassays give a critical apparatus to screening-level appraisals of soil poisonous quality at unsafe waste locales being explored under the Washington Model Toxics Control Act (MTCA) Cleanup Regulation. Until 2001, the main ASTM institutionalized soil test creature was the earthworm, *Eisenia fetida* [27, 28]. The earthworm bioassay is compelling for some applications, however has confinements identified with soil conditions, soil volumes, and the period of time required to play out the test.

Soil parameters (pH, grain measure, natural matter, and supplement levels) ought to be as firmly coordinated as could be expected under the circumstances. Something else, these parameters may impact the result of the test to a more noteworthy degree than the compound tainting itself. It is likewise essential to choose a fitting reference site to get "perfect" soils which can be utilized to relatively weaken site soils for setting up site-particular soil poisonous quality impacts levels.

By far, the most common invertebrate test organisms used to assess soil and contaminant toxicity are members of the Family Lubricidae, as earthworms. Earthworms are important members of the soil fauna and demonstrate a number of traits that make them particularly useful in assessing hazardous materials in soils. Soils are composed of living and nonliving components existing in complex, heterogeneous mixtures. Earthworms maintain close physical contact with all soil components, including other soil biomass (microorganisms, other invertebrates, vegetative material, and detritus). In addition to direct physical contact, earthworms ingest large quantities of soil. Earthworms can constitute up to 92% of total soil biomass and are important in nutrient cycling through breakdown and transformation of organic matter [29].

Earthworms are simple and cheap to keep up in the research center and have insignificant gear and work force preparing necessities. Gear is by and large constrained to suitable compartments and earth controlled space. Other gear might be particular to the endpoints of intrigue (synthetic examination of tissue concentration). The utilization of worms in risk appraisal, along these lines, offers an especially extraordinary chance to evaluate an extensive variety of issues related with risky materials in soils through the control and control of research center (temperature, pH, dampness, and saltiness) and introduction conditions (soil sort and source, contaminants). Evaluation of both direct lethality and bioaccumulation under either intense or constant exposures situations is conceivable in research facility or field conditions.

Since earthworms constitute essential dietary parts in an assortment of vertebrate and invertebrate species, for example, winged animals, well-evolved creatures, reptiles, creatures of land and water, fish, earthworms, and centipedes [30], worm poisonous quality tests can be utilized to evaluate bioavailability and to gauge sustenance web exchange and effects. Significant changes in the wealth of basic soil living beings, for example, night crawlers, could have genuine unfavorable impacts on the biological community. Not exclusively would there be a decrease in their plenitude for species relying on them as a nourishment source, especially amid propagation and raising of posterity, however appropriate exchange of trophic vitality and supplement cycling [27] relies on upon their nearness close to the base of the sustenance web.

The earthworm field test conventions and testing are generally uncommon, and sullied soils can be acquired from the field and utilized as a part of the earthworm lethality tests permitting appraisal of an extensive variety of soil sources. This is especially useful when surveying destinations with known or suspected spatial (horizontal or vertical inclinations or restricted hotspots) or worldly dispersion (pesticide application situations) of contaminants, or when the impact of such components as temperature, pH, dampness, or other soil attributes (molecule estimate, natural substance, and soil substance) are of intrigue or are suspected supporters of soil poisonous quality. Furthermore, fake soils corrected with known contaminants at foreseen field fixations (enlisted name pesticide rates) or in a progression of focuses can be utilized to evaluate potential effects or to look at the relative toxicities of a few chemicals by contrasting figured middle deadly concentrations (LC50). Albeit a few earthworm groups are accessible for testing, the worm species *E. fetida* (the regular redworm) is perceived as a basic test animal category by both national and universal specialists and used in an assortment of endorsed soil harmfulness rules and models [27, 31, 32] and is right now perceived by EPA as species used to screen unsafe waste locales [33].

In spite of the fact that not a run-of-the-mill soil invertebrate, being all the more regularly found in manure rich situations, this species is in any case broadly viewed as illustrative of soil fauna, and night crawlers specifically [34–36] are the most widely recognized research facility species utilized as a part of poisonous quality testing of soils. *E. fetida* exists in two morphologically comparable races, *E. fetida* and *E. fetida andrei*. Both are utilized as a part of testing, in spite of the fact that *E. fetida* is frequently favored. *E. fetida* is especially agreeable to research center testing because of its generally short conceptive cycle. Casings incubate in 3–4 weeks and coming about worms achieve development in two months at 20°C. *E. fetida* is promptly accessible industrially or can be reproduced effectively in the research facility in an extensive variety of rich natural waste materials. It is viewed as exceptionally productive with a cover generation of 2–5 cocoons per worm per week with each cocoon producing several worms. Notwithstanding being an effortlessly kept up research center species, there is an abundance of set up *E. fetida* test information accessible that surveys poisonous quality, proliferation, and bioaccumulation in research center trial of an assortment of natural and inorganic mixes [37–45].

At the point when four types of earthworms (counting *E. fetida*) were contrasted in their affectability with ten organic compounds (speaking to six classes of chemicals), it was discovered that despite the fact that the affectability of various species may fluctuate, the choice of night crawler test species did not particularly influence the compound's general lethality assessment [38]. A gathering of soil fauna researchers from the UK, Denmark, Germany, The Netherlands, and Sweden (and later Poland, Hungary, and the Czech Republic) met to create test frameworks for the early identification and assessment of sub-deadly impacts of chemicals on living beings in soil biological systems. The EU innovative work extend wound up plainly known as SECOFASE, Development, Improvement and Standardization of Test Systems for Assessing Sub lethal Effects of

Chemicals On Fauna in the Soil Ecosystem (1993–1996). The consequence of their endeavors was an essential content entitled Handbook of Soil Invertebrate Toxicity Tests [46].

The nematode can likewise endure a more extensive pH than worms, extending the utilization of soil bioassays. The 24-test length permits oil testing to be finished inside the endorsed test-holding period. The 24-h nematode test comes about have been appeared to be essentially like 14-day worm test comes about [47–50].

Soil poisonous quality tests are vital tests for concentrating on the natural accessibility, development, and impacts of contaminants in an environment. Soil harmfulness tests can likewise be effortlessly used to look at the relative sensitivities of soil living beings to specific chemicals or substance blends. They are especially valuable in contrasting chemicals of concern or in distinguishing and confining spatial and fleeting appropriations of soil poisonous quality. Normal soils are made out of living and nonliving segments in complex heterogeneous blends. Hence, soils gathered in the field are made out of various smaller scale conditions with related redox angles and collaborating physicochemical and organic procedures. Any interruption in these procedures could influence the poisonous quality appraisal of the soil. The nature of the soil poisonous quality test may likewise be influenced by the way of the contaminant of concern.

Testing protocols are regularly composed with methodology and materials that limit the impacts of perplexing elements. As testing mechanical assembly can influence the survival, development, and propagation of the test living being, most test rules distinguish fitting device and hardware to be utilized. Care ought to be taken after the test rules amid studying direct and portray measure methodology and hardware in detail. Substance harmfulness to microbial groups is regularly measured as far as an adjustment in the group's capacity to deteriorate natural matter and discharge plant supplements. Microbial soil poisonous quality reviews are usually led by adding the test material to a soil core containing the actually happening microbial group to survey the impacts of the chemicals on the capacity of the group to keep up its usefulness.

The estimation of adenosine triphosphate (ATP) is at present a standout among the most broadly acknowledged and utilized strategies for measuring microbial biomass [51]. Microbial community health has additionally been evaluated by its capacity to cycle scratch supplements including carbon, nitrogen, sulfur, and phosphorous. The capacity of select microorganisms to mineralize these supplements is basic to biological system prosperity and, on account of a few procedures, for example, nitrification and sulfur oxidation are solely constrained to microbial action. Carbon-change and nitrogen-change systems have been institutionalized and published [52–55].

The in place soil core microcosms are utilized to test the natural destiny and transport, and environmental impacts of chemicals that may enter the earthbound biological community at site-particular or local levels. Understanding that, soil microorganisms lifeforms assume a basic part in soil well-being by separating and changing organic matter. Obstruction in these biochemical procedures could antagonistically influence supplement cycling and soil fruitfulness. Obstruction in these biochemical procedures could antagonistically influence supplement cycling and soil fertility [54]. Soil toxicity tests utilizing plants by and large measure unfriendly consequences for seeds or plants. Impacts on individual plants are utilized to extrapolate conceivable populace or group level impacts. For instance, a few species might be tolerant of a given toxicant, while others are exceedingly delicate. In regular biological communities, changes in species assorted qualities or in plenitude may likewise impact the appropriation and abundance of ward natural life species.

The toxins wind up in soil, where potential dangerous mixes come into direct contact with clays and organic material, which have a high limit with regard for binding to chemical compounds and substances [56]. Numerous creatures that live in soil, including valuable soil fauna, are in this manner routinely presented to elevated amounts of contamination. In these earthbound environments, invertebrates and microorganisms drive a various exhibit of natural and biochemical procedures and assume essential parts in the carbon, nitrogen, and phosphorus and sulfur cycles by separating natural matter. The change of mineralization of organic material is comprehensively imperative for the biological systems and for farming since the cycling of chemicals components gives a lot of plants' nutritious needs.

The anthropogenic effects like the utilization of agricultural pesticides can contaminate the soil which prompts an environmental unevenness in the soil group that may thusly bargain the manageability of the biological system [57]. Utilizing institutionalized soils and its living organisms in a research facility is needed [58].

6 The Development of Soil Ecotoxicology

The natural aggravations are equipped for debilitating the earth as appeared by the climatic changes and the air contamination [59]. How the earth reacts to managed anthropogenic pressures is of awesome significance, where man-made and regular poisons wind up in the biological community with their effects. Safeguarding the earth with regard to a developing human population is vital [60].

The biomass of invertebrates by earthworms assumes an imperative part in organizing the supplement substance of the soil [61–63]. The reasonableness of earthworms as bioindicators in soil lethality is to a great extent because of the way that, they ingest large amount of the decayed litter and organic matter kept on soil [64, 65]. The examination of earthworm biomarkers in environmental hazard appraisal can be useful [66].

Mortality has been the most much of the time utilized parameter to assess the synthetic poisonous quality in the earthworms [67–69]. Negative effect of pesticides on earthworm development has been accounted for by numerous analysts [70–72]. A few reviews have demonstrated that development of earthworms gave off an impression of being more extremely influenced at adolescent stages than at juvenile stage [73, 74]. Various reproductive parameters have been contemplated in earthworm presented to different xenobiotics [67, 69, 75, 76].

A few researchers have revealed that pesticides impact the propagation of worms in dose-dependent way, with more prominent effect at higher concentrations of chemicals

[72, 77–79]. Low proliferation of earthworms was seen in finely sieved soil when contrasted with sandy soil [80], demonstrating that porosity of soil may impact worm portability and vaporous trade, therefore influencing its life cycle. An important aim in earthworm ecotoxicology is to have the capacity to foresee the impact of unsafe chemicals in the field on the premise of research facility tests. The soil biological community is exceptionally unpredictable, where connection happens among abiotic and biotic elements. By finding the impacts of pesticides seen in research center reviews, the impacts in the field studies might be blocked by different ecological factors (climate condition) affecting introduction of earthworms to synthetic [81]. Ecotoxicological thoughts on soil fauna in labs for the most part include a few species. De Silva [82] demonstrated that connecting of the laboratory information to the field might be conceivable and effective [83–86].

Ecological researchers and hazard chiefs welcome that many variables impact the impacts of contaminants on the earth (soil sort, atmosphere, sum and degree of introduction, kind of contaminant, and the number of contaminants, to give some examples) and that no single endpoint examination is probably going to anticipate or decide the profundity and broadness of the natural hazard. Multimetric approaches have for some time been utilized and acknowledged in water quality appraisal [87, 88]. The US EPA's Rapid Bio-assessment Protocols (RBPs) [88] and the Index of Biotic Integrity [89] are two cases of near rating frameworks utilizing various bio-appraisal measurements to give an effortlessly comprehended relative technique. Different bio-assessment techniques, in spite of the fact that not too produced for soils with respect to sea-going frameworks, have for quite some time been suggested as brilliant apparatuses for evaluating compound or contamination impacts, as well as early cautioning frameworks as pointers of ecological corruption [90]. Soil bio-appraisal strategies are accessible and can give basic soil quality information, which can, thus, supplement more conventional synthetic observation to better comprehend the impact of contaminants and debased soils in nature. Specifically, bio-evaluation strategies give in situ data with respect to a definitive and aggregate organic reaction to the natural contaminant in the soil environment.

7 The Soil Profiles

Soil is framed after some time by the parental material (the chemical and physical properties of the beginning rock, alluvium/colluvium, or organic material), the atmosphere (over a significant time span, precipitation, and temperature, for instance), the fauna and vegetation that have lived in it, the help (the geomorphology and its impacts, for instance, on seepage), and time. The soil profile is a portrayal of the vertical cross sections of the soil that actually happen in layers or horizons. These layers or skylines result from soil arrangement and interestingly portray the physicochemical nature of individual soils.

Soil feeders have been considered, however their part in soil procedures is starting to be reported. Subterranean insect species' differing qualities decrease with expanding scope, height, and aridity; they blend little mineral particles in soil with dead natural matter in their guts and contribute by their fecal pellets to soil microstructures [91].

The most punctual meaning of soil was that it is a medium for plant development [1]. Soil debasement is characterized as the procedure, which brings down (quantitatively or subjectively) the current or potentially the potential ability of soil to deliver merchandise or administrations. Soil corruption suggests a relapse in ability from a higher to lower as a crumbling in soil efficiency and land capacity [92–95].

The sustenance crevice because of expanding populace puts more pressure on the utilization of land, bringing about genuine types of land corruption which are viewed as irreversible procedures especially with the serious and proceeded with abuse and poor administration. The heightening of agribusiness combined with poor administration quickens the rate of land corruption. Nourishment supply circumstance will be more awful later on if the present pattern of land corruption does not change radically. The employments of more than 900 million individuals in somewhere in the range of 100 countries are presently straightforwardly and antagonistically influenced via arrive debasement [96]. Unless the present rate of land debasement is moderated and turned around, nourishment security of humankind will be debilitated and the capacity of poor countries to build their riches through enhanced profitability will be blocked. Arrive debasement can be seen in all agroclimatic districts on all landmasses. Albeit climatic conditions, for example, dry season and surges, add to corruption, the fundamental drivers are human exercises. Arrive debasement is a nearby issue in huge number of areas; however, it has aggregate impacts at territorial and worldwide scales. The nations of the creating scene, and especially those in the bone-dry and semi-dry zones, are the most truly influenced [97]. The status of soil corruption is a statement of the seriousness of the procedure. The seriousness of the procedures is portrayed by the degree in which the dirt is debased and by the relative degree of the corrupted zone inside an outlined physiographic unit [98].

8 Pesticides Affect Agriculture and Food Chain

Pesticides are characteristic items or engineered specialists that are utilized to execute pests [99, 100]. As indicated by FAO [101], pesticides are substances proposed to avoid, wreck, or control any pest. The term pesticide incorporates the greater part of the accompanying: herbicide, bug spray, creepy crawly development controller, nematicide, termiticide, molluscicide, pesticide, rodenticide, bactericide, bug repellent, and fungicide. Pesticides are regularly alluded to as per the sort they control. Pesticides can be considered as either biodegradable pesticides, which will be broken down by microorganisms and other living creatures into safe mixes, or tenacious pesticides, which may take months or years before they are broken down [102]. The compound arrangement of pesticides is by a long shot the most helpful grouping to analysts in the field of pesticides and condition and to the individuals who scan for points of interest since it is from this sort of characterization that provides the insight of the physical and synthetic properties of the pesticides. Organophosphates are especially hazardous as they go about as a neurotoxin and impact the brain function.

9 Impact of Toxicity of the Soil on the Agriculture

The most widely recognized and unsafe heavy metals are As, Cd, Pb, Hg, and Ni. Heavy metals are available in air, water, sustenance, and soil. Hg causes discouragement, poor memory, and diminish in sensation; Pb causes headache, touchiness, torment in midriff, and sickliness, and Cd causes kidney harm. The disclosure that soil microorganisms, and specifically the harmonious microbes Rhizobium, were very touchy to heavy metals started another line of research. This has given us essential bits of knowledge into a scope of subjects: ecotoxicology, bioavailability of heavy metals, the part of soil biodiversity, and the presence of living beings [103]. There has been impressive advance in characterizing bioavailability [104] and in assessing contrasts in bioavailability and affectability of soil creatures. The question here is whether poisonous quality impacts were found in here and now lab tests were pertinent to impacts liable to be found in the field? It is recommended that the microbial reactions created in here and now test (intense harmfulness or aggravation) are flighty and looked to some extent like the long haul (unending poisonous quality or stress) impacts seen in the field. Local soil organisms will be all around adjusted to the grouping of metals present in the specific soil [105].

In a few tests, adjustment for poisonous quality to plants, invertebrates, and soil microbial procedures was performed either on soils from arranged field investigations, or zinc or copper angles that had existed in the field for a few years [106–108]. Soil metal concentrations are poor pointers of the genuine fixation in the dirt answer for which soil microorganisms are uncovered. The pH and soil surface that can impact metal bioavailability are considered while building up allowable points of confinement for soil metal focuses [109]. A progression of new reviews has been performed for Zn, Cu, Ni, and Co on microorganisms, invertebrates, and plants utilizing an extensive variety of soils and measurement reactions, and these give full soil portrayal, including the dissolvable metals fixations in the soil arrangement and utilize standard strategies for the bioassays [106, 109, 110]. Microorganisms in the soil live in biofilms, or in microsites on the surface of muds or natural matter, or caught inside micro-aggregates [111]. Zn extractability is really extraordinary [112]. Microorganisms are highly sensitive to heavy metal effects than soil living organism or plants developing on a similar soil without heavy metal [103].

Contrast in species affectability most likely happen in plants, invertebrates, or microorganisms. One of the principal perceptions of metal danger to soil microorganisms in the Woburn Market Garden test was strong decrease in the measure of soil microbial biomass [113–116]. The measure of microbial biomass might be a touchy pointer of metal anxiety, and its reasonableness in natural observing as a marker of soil contamination is restricted on account of its high spatial fluctuation [117]. The expanding metal stress in soils may prompt an expansion or decline in the microbial differing qualities, contingent upon the underlying condition of the framework, and a reaction may happen as regularly observed in natural reviews [103]. Late exploration on harmfulness to free-living Rhizobia in soils has affirmed their relative affectability to substantial metal anxiety [112, 118]. Metal lethality to plants can be anticipated from mass soil properties [109, 110].

Regardless of the expansive group of research on metal poisonous quality to soil microorganisms and microbial procedures, the information were lacking and the understanding was excessively indeterminate, making it impossible to set up hazard based limits [102]. There is an expanding interest for soil bioindicators to decide the condition of soundness of nature [119]. Biological people group designs appear to have the capacity to enroll subjective and quantitative ecological changes because of anthropogenic exercises. There is a reaction of invertebrate's populaces to immediate and roundabout natural anxieties including numerous factors, for example, the ecological anxiety, diverse toxins, and the natural physical elements [119]. Soil invertebrates, particularly earthworm in Orchards, treated with copper sulfate, are influenced in terms of biomass and species populace reaction [120]. The standard research center test strategies as of now accessible are an intense test for surveying earthworm mortality (*E. fetida*) [121], and ceaseless tests for evaluating proliferation of worms [122].

10 Evaluation of Water Soil Toxicity on Agricultural Activities in Egypt

Wastewater irrigation, solid wastes disposal, sludge applications, and industrial activities are the major sources of soil contamination with heavy metals and an increase uptake by food crops grown on such contaminated soils is observed. Heavy metals contain harmful substances which are making openings and issues for agricultural production [123, 124]. Over the top aggregation of heavy metals in rural soils through wastewater system may bring about soil contamination as well as contamination but also lead to elevated heavy metals uptake by crops and thus affecting the quality and safety of food.

Substantial metal accumulation in soil and plants is of expanding concern in view of the potential human well-being dangers. This evolved way of life tainting is one of the imperative pathways for the passage of these poisonous toxins into human body. Substantial metal contamination in plants relies upon the plant species and the effectiveness of various plants in engrossing metals is assessed by either plant take-up or soil-to-plant exchange of elements of the metals [125].

10.1 Some Solutions of the Impact of Toxicity of the Soil on Agriculture

Various bacteria, fungi, and algae have been isolated for the breakdown of fragrant hydrocarbons as carbon and vitality sources in different investigations [126, 127]. Bio-remediation of pollutants utilizing the microorganisms capacity to corrupt ecological toxins incorporates regular lessening which can be improved with building procedures. There have been various examinations with respect to the debasement of ecological toxins utilizing microorganisms. A few microbes are known for the way that they expend just hydrocarbons. The biodegradation of hydrocarbons should be possible vigorously or anaerobically utilizing bacteria, for example, *Pseudomonas* and *Brevibacillus* disengaged from the dirt that was dirtied with oil. The smaller scale living beings that are utilized as a part of bioremediation are generally indigenous; in any case, microorganisms that are segregated from somewhere else and immunized on sullied soils can likewise be utilized. The last items can be carbon dioxide, water, and more straightforward mixes which do not harm the earth [128].

Pseudomonas putida strain affirms that the types of this variety are equipped for bio-remediating the polluted soils through the disintegration of hydrocarbons and their utilization as nourishment source. The *Bacillus subtilis* strain yielded palatable outcomes for the bio-remediation of soils dirtied with diesel fuel [129]. Soil tainting with overwhelming metals is overall ecological worries because of unfriendly consequences for the human well-being, sustenance, security, and on the biological system [130]. Soil remediation techniques are earnestly required to remediate overwhelming metals-debased soils for safe sustenance generation [131, 132]. Studies have affirmed that the part of plant-inferred squander biochar in the immobilization of soil overwhelming metals consequently lessened their lethality from soil plant framework [133–136].

Bain et al. [130] announced that phosphorus-bearing materials diminished the rate of corrosive dissolvable part of Pb, while expanding the oxidizable Pb division because of sorption of Pb on phosphorus mineral surface. The highly significant increase in Pb concentration is conceivably because of the precipitation of Pb-phosphate (Pb-P) [137]. The following metals in corrosive solvent stage are viewed as more versatile and bio-dangerous than different parts [138]. Rice straw as one of the significant harvest deposits uncovered a capacity to remediate the substantial metals from squander water and watery solution [139]. Rice straw adsorbs more Pb at pH 2.0 [140].

11 Conclusion

The centralization of substantial metal which will slaughter a sea-going and additionally an earthly living being is exceptionally reliant both on the metal and on the life-form. The request of poisonous quality is not unbending and is distinctive in various species. Once in a while, one metal might be more harmful than another at low fixations and less poisonous at high focuses. Sessile life-forms which cannot stay away from changes in the earth might be more tolerant than different life-forms. Helplessness may rely on upon the porousness of the creature to various metals or to its nourishing living spaces or to the proficiency of its administrative or detoxification framework. The estimation of poisonous quality has numerous actualities; the absolute most essential of these can be identified with the attributes and states of introduction. These are identified with time and recurrence of introduction, the course with which presentation happens, and the measurements conveyed including the physical and concoction type of the toxin. Among the altered materials, the rice straw application was observed to be successful to immobilize Cu and Pb in defiled soil. Biochar can possibly diminish leachability and bioavailability of substantial metals in the dirtied soil. Rice straw was observed to be compelling to diminish the bioaccessible substantial metal rates. The examination on microflora is essential as a bioindicator for soil polluted by hydrocarbon. Detoxification and improved expulsion of poison from the living beings after retention are conceivable on account of different metal intoxications. There are natural aggravates that frame chelates with different metal particles with certain level of selectivity. In this procedure, the metal particle loses its ionic character and generally its poisonous quality too. The poisonous quality of overwhelming metals depends on cooperation between the particles of these metals and different basic gatherings in practically vital proteins.

12 Recommendation

Facilitate examination would be required to give knowledge the impact of biochar on different dangerous metals under dirtied field conditions. The bioaccumulation of toxins can happen from water, air, and through the natural pecking order. The rate at which aggregation happens relies on the accessibility of the contaminations, ecological conditions, and living beings' capacity to acclimatize it. One of the rule targets in the treatment of harming by overwhelming metals is expulsion of the dangerous metal from the body by organization of chelating specialists. Fruitful treatment for intoxication by substantial metals includes arrangement of a moderately stable chelates–metal complex which is transported by means of the course to the kidney and excreted. The stability of overwhelming metals by rice straw in tainted soil should be surveyed exceptionally under normal defiled fields. The impact of chelating specialists like EDTA, on the poisonous quality and dissemination of substantial metals in man and creatures, has likewise been examined.

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Part III
Potential Application of Crop Productivity

Potential Role of Intercropping in Maintaining and Facilitating Environmental Sustainability

Hassan Awaad and Nehal El-Naggar

Contents

Abstract Intercropping plays an important role in increasing productivity and achieving sustainability in agriculture and animal production by accounting for social, economic, and environmental considerations. This approach should be the basis of any economic construction, particularly in developing countries such as Egypt. Intercropping improves the use efficiency of land and available resources (water, light, and nutrients) through the different stages of growth. Furthermore, intercropping is a proven method to deter pests, encourage the proliferation of their natural enemies, reduce disease and insect injury, and inhibit weed growth through a "push–pull" system, making it an important aspect of sustainable agriculture. Integration and facilitation of available resources can occur through the different

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stages of growth in several intercropping systems. Also, the benefits from intercropping for a unit area can be maximized through the activity of microorganisms and nitrogen fixation to obtain a land equivalent ratio greater than 1. Terminal restriction fragment length polymorphism (T-RFLP) molecular marker profiling has been used to fingerprint the 16S rRNA gene and identify the relative abundance of bacterial populations in the rhizosphere of intercropping patterns. This can reduce nitrate washing, as well as the risk of groundwater contamination by nitrates.

Keywords Crop productivity, Environmental resources, Intercropping patterns, Nitrogen fixation, Pest control, Sustainability

1 Introduction

Approximately 37 countries – 28 of which are in Africa – require external assistance for food [1]. Grain producers should implement sustainable agricultural practices to meet today's unprecedented demands for corn, rice, and wheat in these locations. Sustainability, which can be defined as the ability to continue a defined behavior indefinitely, has three pillars: social, environmental, and economic.

Since the earliest times, humans have moved from one place to another in search of food and clothing, as well as to meet the needs of their livestock. Humans began cultivating food, but they did not follow a particular system. With the passage of time, they noticed that land productivity decreased after growing a particular crop in the same location for several years. Because of this declining soil fertility, humans would abandon this land for several years, allow it to recover its ability to support agriculture. Eventually, the value of leguminous crops for the renewal of agricultural land was discovered, along with the relationship between legumes and *Rhizobium* bacteria to atmospheric nitrogen fixation. This unveiled the capability of the legume crop to restore soil fertility and its importance in cropping patterns, intercropping systems, crop rotations, and sustainable agriculture systems.

With scientific developments and intensification of farming systems, increasing attention has been paid to intercropping. Intercropping offers a wide range of productivity, economic, social, and environmental benefits to farmers and society. These benefits include increased productivity, increased profitability, improved ecosystems, and reduced greenhouse gas emissions from human activities and the carbon impact of agriculture [2].

In sustainable agriculture, legume crops play an important role in intercropping patterns by delivering multiple benefits in line with sustainability principles [3]. Legumes are a fundamental, global source of high-quality food and feed. They help to reduce the emission of greenhouse gases (GHGs), as they release 5–7 times less GHG per unit area compared with other crops. Legumes also allow the sequestration of carbon in soils, with values estimated to be 7.21 gross kilograms $(gkg)^{-1}$ dry matter, 23.6 versus 21.8 $gCkg^{-1}$ year.

Adequate food production has been an important goal defining the agricultural production style of the the Arab Republic of Egypt in recent years. A food gap was created when a massive population increase was not accompanied by a parallel increase in the agricultural production of food crops such as cereals, oils, and sugar. Hence, interest has increased in cultivating areas of different crops, either through horizontal expansion with reclamation of new land or through vertical expansion with high-yield varieties, which uses non-traditional patterns to increase the agricultural area (also known as agricultural intensification). Intensification, sustainable utilization of land resources, and maximization of the unit area productivity could be achieved through various cropping patterns in an integrated farming system, especially using crops of economic importance to increase the productivity per unit area and integrate with livestock and poultry production.

Intercropping is defined as the simultaneous cultivation of multiple crop species in a single field (Fig. 1). Intercropping leads to increased aboveground productivity due to a complementary sharing of plant resources, diversity and stability of fields, reduction in chemical/fertilizer application (e.g., using nitrogen from nitrogen-fixing plants), weed suppression, and a reduction in susceptibility to insects and disease.

Most researchers in the field of crop science aim to increase the productivity of intercropping units. From the point of view of plant breeders, productivity is the outcome of the interactions between the genetic makeups of the intercropping system and ambient environmental conditions. Therefore, the positive effects of intercropping include the maintenance of soil water and utilization of the available environmental resources; it is also facilitated through the activity of microorganisms and nitrogen fixation. Therefore, intercropping can lead to improvements in the physiological and biochemical characteristics of the plant rhizosphere, which in turn increase productivity. The beneficial effects of intercropping can also encourage the proliferation of natural enemies, reduce disease and insect injury, and inhibit weed growth – all of which undoubtedly lead to positive effects for the final products of the intercropping unit area under sustainable agriculture [5]. Multiple benefits can be obtained from the application of different intercropping systems, which can improve soil conditions and the environment in which the plant grows and thus increase crop productivity.

Fig. 1 Intercropping soybeans with maize [4]

2 Role of Intercropping in the Maintenance of Soil Water and Utilization of the Available Environmental Resources

Food shortages are a major problem in developing countries, such as Egypt. "Agricultural development is facing several constraints, including limitations on soil, water, and inputs". Othman and Hassan [6] added that as population growth continues, the production per unit area will also decrease. Therefore, the adoption of agricultural intensification is imperative in light of the continuously changing variables that are becoming more challenging each year. In Egypt, intensification aims to optimize the use of all available resources to attain the highest possible productivity per unit of land area, which can be achieved using intercropping as an agricultural intensification system. A cereal/legume intercropping system may increase soil fertility by raising its organic content and the available nitrogen that is fixed by the legumes, thus saving water, reducing input requirements, reducing the need for costly inputs, and ensuring agricultural sustainability.

Water is the medium in which vital physiological processes are carried out. Plants growing in soil have a variety of morphological and physiological root characteristics, such as length, intensity, spread, flat contact, and depth, through which they receive the benefits of available environmental resources. Intercropping can preserve the soil water through shading, reduced wind speed, increased porosity of the surface layer, and improved soil structure. The location of different root systems in intercropping patterns affects the absorption of water and the ability of each component to compete for water sources. In Egypt, intercropping barley/chickpea or lupin in 2:1 and 2:2 systems resulted in a land equivalent ratio (LER) of more than 1, indicating a yield advantage over a single crop due to better land utilization [7]. This is due to the shading of the soil surface and increased density of the canopy, resulting in less soil surface evaporation. Thus, there is a complementary use of water recourses by both species in the intercropping system.

The effects of intercropped maize with cowpea on the distribution of light, temperature, and soil moisture have also been studied [8]. Intercropping was found to increase the proportion of light receptors in intercropped plants, decrease the evaporation of water, and improve the soil moisture content compared to single-crop agriculture.

In a study by Abdel-Wahab et al. investigating compatible soybean cultivars with high maize plant density to achieve agricultural benefits under intercropping conditions in Egypt, alternating ridges (70 cm in width) were used between the maize and soybean crops in 1:3, 2:4, 2:2, 3:3, and 4:2 patterns. The late-maturing soybean cultivar Giza 22 recorded the highest values for intercepted light intensity within the soybean canopy, the number of pods per plant, seed index, seed yields per plant, and seed yields per hectare. Of the soybean cultivars, Giza 22 resulted in the highest seed yield per plant compared with Giza 82 and Giza 111 under different intercropping patterns. However, the early-maturing soybean cultivar Giza 82 was better suited for low light intensity than the other cultivars. The LER and area time equivalent ratio values for the intercrops were greater than 1.00, indicating that there were lower land requirements for intercropping patterns than for only maize. Four maize ridges alternated with two ridges of Giza 82 achieved the highest net return compared to maize alone [9]. This information confirms the importance of intercropping in improving soil and plants characteristics and maintaining environmental resources.

3 Role of Intercropping in the Integration and Use of Environmental Resources

Intercropping has several advantages over solid cropping with regard to the integration and use of environmental resources. Specific competition and facilitation occur at the same time in some intercropping systems. When the benefits for a unit area are maximized, land equivalent ratio values are greater than 1. These benefits are due to the integrative effects more than the effects of interaction and competition. For example, the leguminous crops used in mixing systems, such as cowpea fodder and ivy, are characterized by carbon-to-nitrogen ratios of 31–35; in comparison, non-leguminous coverage crops, such as millet and Sudan grass, have carbon-to-nitrogen ratios of that are greater than 50. The decomposition of crop coverage legumes dramatically increase the activity of microorganisms in response to the availability of plant residues. Therefore, legume crops can provide nitrogen to non-legume crops through the activity of mycorrhizal fungi, the decomposition of root and bacterial nodules, or air-nitrogen fixation, which reduces competition for soil nitrates by the non-legume crops.

Urbatzka et al. [10] showed that the amount of nitrogen lost by washing is reduced when peas are cultivated with a mixture with cereal crops versus peas alone. The authors also found that nitrogen utilization efficiency in mixed cultivation was greater than for peas alone. The positive effects of an intercropping system were confirmed by Callaway [11] investigated the ability of intercropping species to change the biotic and abiotic environments of the root system and further facilitate nutritional elements. Zhang and Li [12] reviewed research on the processes involved in the yield advantage of wheat (*Triticum aestivum* L.)/maize (*Zea mays* L.), wheat/soybean [*Glycine max* (L.) Merr.], faba bean (*Vicia faba* L.)/maize, peanut (*Arachis hypogaea* L.)/maize and water convolvulus (*Ipomoea aquatica* Forsk.)/maize intercropping. In wheat/maize and wheat/soybean intercropping systems, the authors reported compensatory growth, or a recovery process, in subordinate species such as maize and soybean, offsetting the impairments associated with the early growth of these subordinate species. In addition, interspecific facilitation was observed, in which maize improved iron nutrition in intercropped peanut, faba bean enhanced nitrogen and phosphorus uptake by intercropped maize, and chickpea facilitated phosphorus uptake by associated wheat from phytate-phosphorous.

Intercropping is an ideal cropping system, with better light interception, soil moisture, soil temperature, and yield than sole crops [8]. Perhaps the most obvious example of this integration is the use of nitrogen between cereals and nitrogen-fixing legumes, where both types compete for light and soil nitrogen. Malezieux et al. [13] showed that mixed crops achieved better use of light energy and had other advantages due to benefits from growth elements, such as water and nutrient elements, being provided in a more integrated manner. These elements can be integrated and converted into dry matter in the intercropped system. This due to variations in plant characteristics, such as development of the canopy size, the harmonization of the canopy for photosynthesis, light radiation conditions, and deep root system. Moshira El-Shamy et al. [14] found that intercropping soybeans with maize provided more space for adjacent maize plants to grow and increased light intensity within the soybean canopy.

The components of intercropping are integrated by exploiting through its root systems in the different layers of the soil. Experiments conducted in Germany showed that the accumulation of phosphorus and sulfur increased by approximately 20% in intercropping system (50% legumes/50% grains) compared to sole farming of these crops [15]. However, in field experiments that intercropped millet with pigeon peas and castor, nitrogen and phosphorus absorption were affected by farming systems, with the absorption of nitrogen and phosphorus being highest in sole millet rather than in millet intercropped with pigeon peas and castor [16]. Microclimatic variations in intercropping system have created favorable environmental conditions that are more favorable for growth and high yields than sole crops.

The importance of biological nitrogen fixation a primary source of nitrogen for agriculture has diminished in recent decades as increasing amounts of nitrogen fertilizer have been used for the production of food and cash crops. The net income of Egyptian farmers has increased through the use of suitable agricultural practices, such as intercropping that improves wheat plant efficiency by using biological nitrogen fixation from associative legume crops. Intercropping can result in greater-than-expected yields from the enhanced use of environmental resources, such as nutrients. Pea and legume crops play an important role in biological nitrogen fixation, such as pea plants modulated by *Rhizobium leguminosarum* bv. *viciae*. Sheha et al. [17] showed that "[a] pea–wheat intercropping system is considered well adapted under Egyptian conditions and could be an alternative way to decrease N inputs of wheat by about 25% through increasing nitrogen use efficiency (NUE) of wheat. Also, intercropping pea with wheat increased net income by US$2547/ha compared to sole wheat." NUE was affected significantly by mineral nitrogen fertilizer doses and pea sowing dates (Fig. 2). Wheat plants that received 133.8 kg N/ha exhibited the highest NUE compated with the corresponding plants that received 178.5 kg N/ha.

Intercropping plays an important role in improving multiple agroecosystem services by increasing yield, soil quality and soil carbon sequestration. In this respect, Cong et al. [18] demonstrated a divergence in soil organic carbon and nitrogen content over 7 years in a field experiment that compared rotational strip

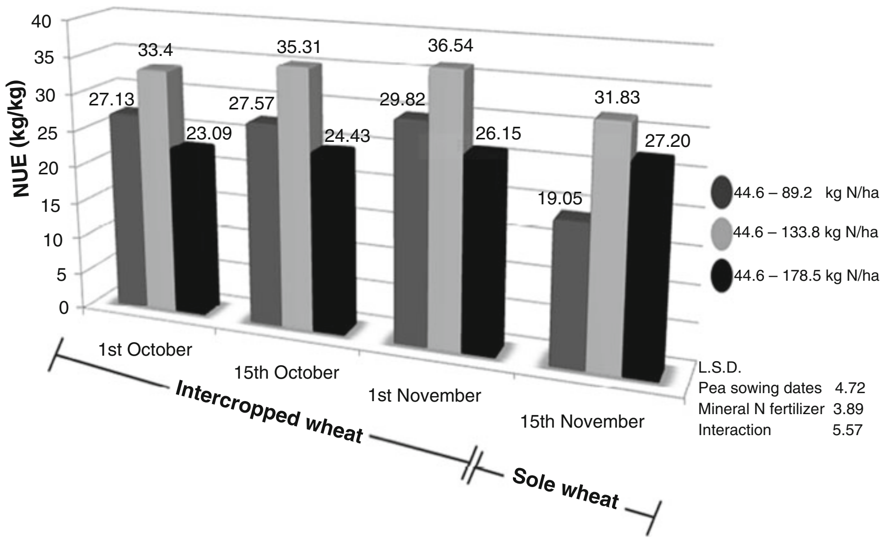

Fig. 2 Nitrogen use efficiency (NUE) as affected by pea sowing dates, mineral nitrogen fertilizer, and their interaction, based on combined data from the 2012/2013 and 2013/2014 seasons [17]

intercrop systems and ordinary crop rotations. They found that soil organic carbon content in the top 20 cm was 4 ± 1% greater in intercrops than in sole crops. Soil organic nitrogen content in the top 20 cm was 11 ± 1% greater in intercrops than in sole crops. Total root biomass in intercrops was on average 23% greater than the average root biomass in sole crops. The authors recorded a decrease in the $\delta^{15}N$ of soils due to increased biological nitrogen fixation and/or reduced gaseous N losses, leading to increases in soil nitrogen in intercrop rotations with faba beans. Increases in soil nitrogen in wheat/maize intercrops pointed to contributions from a broader suite of mechanisms for nitrogen retention, such as complementary nitrogen uptake strategies of the intercropped plant species.

Under Egyptian conditions, Moshira El-Shamy et al. [14] grew local maize cultivar T.W.C. 310 under intercropping and solid cultures in one row/ridge and two hill-spaced plants at 30 and 60 cm, respectively, which received one of three mineral nitrogen fertilizer rates (4, 5, and 6 g N/plant); soybean variety Giza 82 was drilled in two rows/ridge. The authors found that light intensity within the maize canopy, ear leaf nitrogen, and indole acetic acid (IAA) content were affected by all of the studied factors. Intercropped soybeans led to improved NUE for maize plants. The mixed pattern had a total yield increase of 29.79% compared with solid maize. Growing soybeans on both sides of the maize ridge with two hill-spaced plants at 60 cm decreased the recommended mineral nitrogen rate of the maize plants by 47.6 kg N/ha, which represents the best bioengineered treatment. In addition to these beneficial effects, environmental studies have confirmed that intercropping improves the movement and absorption of phosphorus [19], as well as the movement of potassium and micronutrients through specific interactions occurring in the rhizosphere [20]. Furthermore, intercropping reduces nitrate washing and reduces nitrate groundwater contamination [21].

4 Role of Intercropping in Improving the Physiological and Biochemical Characteristics of the Soil and Plant

In sustainable agriculture, intercropping helps to improve the root environment. A significant decrease in the acidity of the soil pH environment has been observed near alkaline plants, as a result of the synthesis of organic acids in the leaves and transfer to the roots, leading to reduced pH of sodic soil. This process provides a suitable environment for plant growth and high yields. Based on this concept, a low-pH soil environment for sugar cane genotypes can play an important role in intercropping systems with mustard, peanuts, and garlic. Therefore, intercropping peanuts with sugar cane can enrich the soil with nitrogen and potassium. Intercropping cowpea with corn provides nitrogen, phosphorus, potassium and calcium; it also plays a role in overcoming the acidity of the soil and thus increases productivity in sustainable agriculture compared to solid crops [22]. Lamlon et al. [23] studied the residual effects of three winter crops (berseem, sugar beet, and wheat) on yield, as well as the attributes of intercropping the soybean cultivar Giza 22 with three maize cultivars (S.C.122, T.W.C. 310, and Giza 2) in 2:2 alternating ridges. Berseem had promoting effects on the chemical and biological soil properties of a soybean-maize intercropping system in the following season; it also led to increased soil nitrogen availability in the soybean root environment. Crop residues that had positive allelopathic effects on soil properties contributed to the productivity of intercropped soybeans with maize. Intercropping soybeans with the T.W.C. 310 cultivar that followed berseem cutting produced 1.78 ton/ha of soybean seeds in addition to 5.60 ton/ha of maize grains, achieving yield advantage because the LER exceeded 1.00 with the highest monetary advantage index. The berseem crop residues enhanced the efficiency of the soybean plant's photosynthetic process, which has positive effects on the dry weights of the leaves, pods, and plant at 85 days after sowing. Also, improved soil phosphorous availability positively affected the dry weights of the leaves, pods, and plant of soybean. This also played a major role in the soybean plant's photosynthetic process through the observed increase in leaf nitrogen, chlorophylls *a* and *b*, and total chlorophyll after berseem cutting. Also, there was more soil K, Fe, Mg, Mn, and S availability after berseem cutting, which enhanced soybean growth and development.

Lamlom et al. [23] added that plant growth promoting *Rhizobacteria* increased soybean plant growth indirectly by modifying nodule formation and biological nitrogen fixation. Forage legume (berseem) residues promoted plant growth and *Rhizobacteria*, which included nitrogen-fixing bacteria (*Rhizobia* sp. and *Azotobacter* sp.), *Bacillus* sp., and phosphate-solubilizing bacteria more than those by sugar beet or wheat. Berseem residues might increase the physiological strength of the soybean plant by increasing chlorophyll and the effective life of the leaves.

In this respect, Sheha et al. [17] found that intercropping wheat with pea sown on 1 October resulted in a significant increase in the fresh weight of flag leaf blade, flag leaf blade area, flag leaf blade nitrogen content, chlorophyll content, and whole plant dry weight by 6.96%, 15.38%, 4.59%, 4.07%, and 10.58%, respectively, compared with those sown on 1 November. These results could be due to the earlier sowing date of pea-promoted rhizobia growth in rhizosphere of wheat roots compared with intercropped pea that was sown on 15 October or 1 November. However, the biological nitrogen fixation process of peas could help to cover the nitrogen needs of wheat as a cereal component; when grown at 15 cm from the pea row, it enhances rhizobia growth in the rhizosphere of wheat roots during wheat development. The flag leaf traits and dry weight of the whole plant sown at 45 cm from the pea row were not affected significantly by the pea sowing dates at 140 days from wheat sowing in the combined data. The microbial soil activity in the rhizosphere of intercropped wheat roots with peas grown in the third row had the same biological interactions in the rhizosphere as sole wheat roots (Table 1).

Intercropping and its relationship to enzymatic activity were studied in China by Liu et al. [24], who showed that proper intercropping of maize with different genotypes increases the activity of the superoxide dismutase, peroxidase enzymes, and catalase in the leaves and increases leaf duration, yield, and quality. Sun et al. [25] intercropped alfalfa with the Siberian perennial ray under different treatments, including intercropping, intercropping with the inoculation of *Rhizoubium*, and solid agriculture. The authors noticed that intercropping with the *Rhizoubium* inoculation resulted in qualitative differences in enzyme activity in the rhizosphere soil for both crop fodders. Both intercropping approaches led to a significant increase in the activity of the urease enzyme (10.56% and 15.65%, respectively) and invertase enzyme activity (16.27% and 19.34%, respectively) in the rhizosphere of alfalfa compared to a single crop. Alkaline phosphatase activity was also significantly increased in intercropping with *Rhizoubium* inoculation, but a significant decrease was found in the activity of alkaline phosphatase enzyme and invertase in the rhizosphere of ray in both intercropping and intercropping with *Rhizobium* inoculation. Urease enzyme activity was similar in both intercropping treatments compared to a single crop. Li et al. [26] showed that soil nitrate reductase activity in a maize/faba bean system was significantly higher than in corresponding solid cropping. This is due to the increase in soil nitrogen content due to improved nitrogen fixation by faba bean intercropped with maize.

Table 1 Total rhizobia count in the rhizosphere of wheat roots in the first row under intercropping and sole cultures [17]

Pea sowing dates	Total count of rhizobia (cfu)			
	44.6 kg N/ha	89.2 kg N/ha	133.8 kg N/ha	178.5 kg N/ha
Intercropping pea with wheat				
1 October	1.8×10^3	2.3×10^5	5.1×10^5	4.3×10^5
15 October	1.5×10^3	2.2×10^5	4.7×10^5	4.1×10^5
1 November	1.5×10^3	2.1×10^5	4.3×10^5	3.9×10^5
Sole wheat	1.1×10^3	1.5×10^3	1.5×10^3	1.5×10^3

5 Role of Intercropping in the Activity of Microorganisms, Fixed Atmospheric Nitrogen, and Readily Available Soil Phosphorus

Biological nitrogen fixation is a major source of nitrogen input in soils, especially in arid zones. It can improve the fertility and productivity of low-nitrogen soils in sustainable agriculture. *Rhizobium*-legume symbioses in particular have been examined extensively in the literature. Hassanein et al. [27] conducted a field experiment at Abou Masood Village (48 km southwest of Alexandria) in normal calcareous soil with a sandy clay loam texture. Intercropped soybean (Clark variety) and maize were crossed in four systems (100% soybean, 67% soybean/ 33% maize, 50% soybean/50% maize, and 100% maize). Treatments included the inoculation of soybean seeds with *Rhyzobia*, the top dressing of maize with ammonium sulfate, and spraying with urea-diammonium phosphate or diluted phosphoric acid in a split plot design. Intercropping was more beneficial than solo cropping for soybeans in terms of increased seed yield, harvest index, pod filling, nitrogen and phosphorous amounts in seeds and straw, and the harvest index of maize, the nitrogen and phosphorous concentration in grains and stover, and the phosphorous in grains. The system that consisted of two rows of soybean plants (16,000 soybean plants) with a row of maize (7,000 plants) improved soybean conditions more than the row:row system in which 12,000 soybean plants were associated with 10,500 maize plants; however, the latter system was better than the 2:1 system for maize. When comparing the inoculation of soybeans with *Rhyzobia*, the fertilization of maize with 60 kg N/fed with ammonium sulfate, and solo cropping, intercropping systems had the best yields of soybean seeds, straw, maize grains, and stover as well as nitrogen and phosphorous uptake by them.

Abd El-Gaid et al. [28] conducted their field experiments in sandy soil with a drip irrigation system at the Regional Agricultural Research Station, New Valley, El-Kharga Governorate, Egypt. Tomato cv. Super Strain B was the main crop; it was intercropped with different plant population densities of common bean cv. Bronco. Treatments consisted of combinations of three different densities (for each tomato plant, either one, two, or three common bean plants) in a randomized complete block design. Results indicated that the greatest increase in profits would occur in the system of one plant tomato per three common bean plants. Also, the highest LERs were reported for this system, at 1.26 and 1.25 in the first and second seasons, respectively. This advantage could be due to the nitrogen fixation effect of the common bean crop, which increases soil fertility and enhances plant growth and the branching process. Thus, this pattern is recommended to improve income and LER under New Valley conditions.

The terminal restriction fragment length polymorphism (T-RFLP) technique for fingerprinting the 16S rRNA gene has been used to identify and estimate the populations of main bacteria. Sun et al. [25] intercropped alfalfa with the Siberian ray perennial under different treatments: intercropping, intercropping with inoculation by *Rhizobium*, and solid agriculture. The analysis showed the presence of steady systems, as well as the profile Haelll. The first primary component in principal component analysis (PCA) explained 37.4% of the variance and the second essential component explained 25.4% of the total variance. The authors detected clear differences in the composition of the bacteria communities between the plants; relatively greater similarity was noted for alfalfa compared with the wild Siberian ray. For the wild-ray, genetic analysis showed that intercropping and solid agriculture were gathered in one group cluster, whereas intercropping treatment with inoculation had a strong influence on the population and rhizosphere in the Siberian ray perennial community. Using T-RFLP technology of subunits A of ammonia monooxygenase gene (*amoA*), the authors determined the existence of *Nitrosomonas* and *Nitrospira* in all treatments, with declining relative abundances in two sets of groups *Nitrosomonas* and *Nitrospira* for intercropping with inoculation by *Rhizobium*. Both intercropping treatments led to increased diversity of the gene (*amoA*); they also affected the microbial composition and enzymatic activity of the soil. This is reflected in the increased yield in intercropping with inoculation by *Rhizobium* compared with only intercropping; the solid treatment had the lowest yield. These findings show that the beneficial effects of intercropping enhance the activity of soil microorganisms.

6 Role of Intercropping in Controlling Insects and Encouraging Natural Enemies

As stated by Pretty and Bharucha [29], integrated pest management is a leading complement and alternative to synthetic pesticides and a form of sustainable intensification with particular importance for tropical farmers. However, integrated pest management approaches will benefit not only farmers, but also wider environments and human health.

Africa faces serious challenges in feeding its population, mainly due to poor yields of cereals; these staple and cash crops are negatively affected by insect pests, weeds, poor soil fertility and, more recently, the effects of climate change. To address some of these issues, Khan et al. [30] proposed the use of a "push–pull" system, which combines the principles of sustainability and biological control. This new approach to pest management uses a repellent intercrop and an attractive trap plant. It was developed to control stemborers and striga weed in resource-poor maize farming systems (Fig. 3). In this system, maize was intercropped with the legume silverleaf desmodium, while Napier grass was planted around the intercrop. The desmodium produced volatile chemicals, such as (E)-ß-ocimene and (E)-4,8-dimethyl-1,3,7-nonatriene, which repelled stemborer moths from the maize ("push"); meanwhile, the chemicals released by Napier grass, such as octanal, nonanal, naphthalene, 4-allylanisole, eugenol, and linalool, attracted female moths ("pull") to lay eggs. Desmodium roots produced chemicals that stimulated Striga seed germination, such as 4′,5′-dihydro-5,2′,4′-trihydroxy-5′-isopropenyl Furano-(2′,3′;7,6)-isoflavanone,

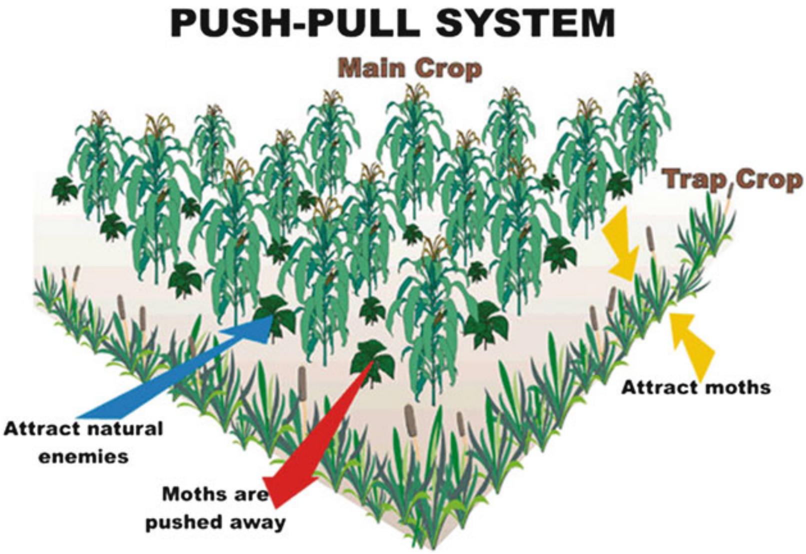

Fig. 3 A push–pull strategy for insect pest management [30]

and others, which prevented association with the roots of maize, thereby reducing the seed count of Striga. The desmodium also increased soil fertility through biological nitrogen fixation.

Push-pull systems have been used on more than 55,000 farms in Kenya. This technology has also spread to Ethiopia, Tanzania, and Uganda to help fill the food gap [31, 32]. The technique has increased maize yields by 15–20% in Kenya. In the semi-arid Suba district, which is plagued by both stemborers and Striga, a substantial increase in milk yield also occurred in 4 years, with farmers now being able to support more dairy cows with the fodder produced. When farmers planted maize together with the push–pull plants, their return was US$2.30 for every dollar invested, compared with US$1.40 obtained by planting maize as a monocrop [29].

A study in Egypt [33] also found that intercropping medical and aromatic plants such as dill, barley. and coriander with bean plants caused a high reduction in the populations of aphids, whiteflies, and mites to levels that did not require any type of chemical control. Furthermore, the population density of the natural enemy *Coccinella undecimpunctata* increased in the experimental field as a result of intercropping, and there was a correlation between the occurrence of these enemies and the reduction of pests. Moreover, intercropping cowpea with maize in an agro-ecosystem can act as a reservoir for naturally occurring biological control agents [34], as shown in Fig. 4. In this respect, faba bean plus fenugreek or coriander intercropping reduced populations of *craccivora* for faba bean. Field trials in Sohag, Egypt [35] during tow cropping seasons were conducted to determine the effects of intercropping of faba bean with coriander, fenugreek, or onion crops on the population of *Appis craccivora* and the yield of faba bean. The population of the

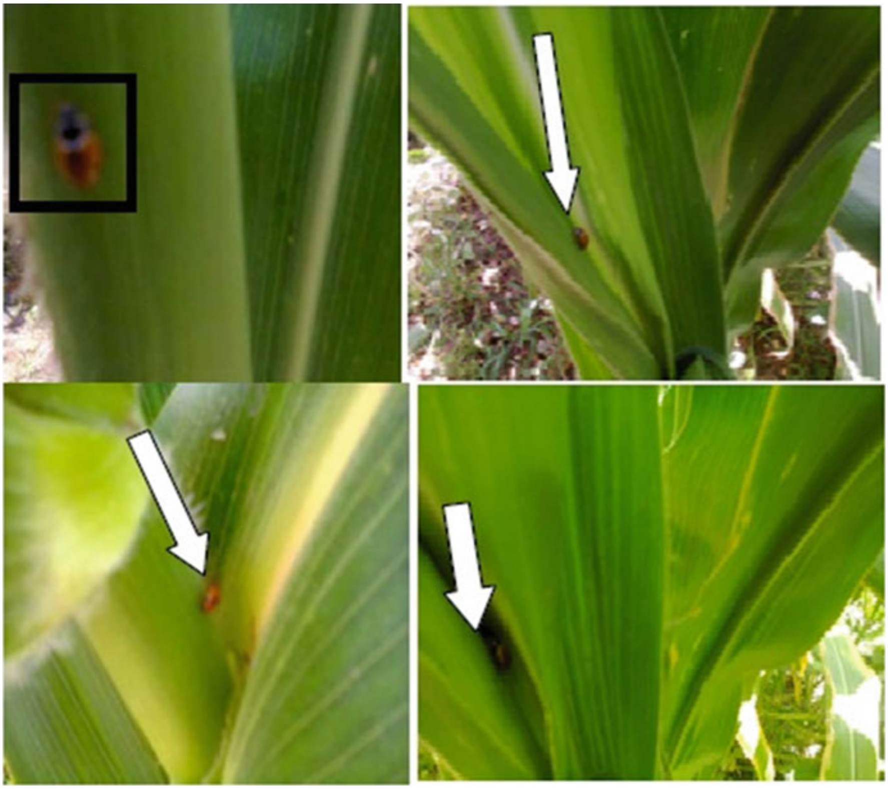

Fig. 4 Spotted ladybird on maize plants intercropped with cowpea [34]

aphids was significantly lower for the faba bean + fenugreek intercrop in the first cropping season and lower for the faba bean + fenugreek or coriander intercrop in the second cropping season than for the faba bean + onion or faba bean crop only. The study results showed that the faba bean + fenugreek intercrop reduced populations of *A. craccivora* and the increased seed yield of faba bean crop.

7 Role of Intercropping Systems in Disease Control

Intercropping plays an important role in the biological control of agricultural diseases. The importance of intercropping faba beans with canola to avoid the risk of fungal infections has been reported previously [36]. The components of intercrops seem to be less damaged by disease organisms than solid agriculture. Disease escape in intercropping systems occurs in three ways: (1) the associated plants of the attacked component are less preferred by the causal organism; (2) they interfere directly with pathogen activities; and (3) they change the environment in the intercrop, in a way that encourages the spread of natural enemies. For example, Montaser et al. [37] reported a significant reduction in damping-off and root rot caused by *R. solani* and/or *F. solani* when lentil plants cv. Giza 9 were intercropped with cumin, anise, onion, and garlic. The highest reduction in damping-off severity was noted when lentil was intercropped with anise grown in soil previously infested or inoculated with the pathogenic fungi. Intercropped garlic also decreased disease in the lentil, with lesser effects reported when lentil was intercropped with onion and cumin. When was lentil cultivated after cowpea, the highest seed yield was achieved, followed by gaur and millet. The lowest population of the causal organism *R. solani* was observed when cowpea was cultivated before lentil; cultivating sorghum before lentil resulted in the lowest population of *F. solani*. The root exudates of intercropping and preceding crops led to reduced mycelial dry weight of the tested fungi in vitro, except for groundnut and soybean.

Greenhouse and field experiments [38] studied the effects of intercropping on three Egyptian cultivars of faba bean (Giza 3 Mohassan, Giza 40, and Sakha 1) with wheat cultivar (Sakha 93). The application of phosphorus fertilizer (100 and 200 kg/fed) before planting caused a reduction in the incidence and disease severity for the three cultivars of faba bean in greenhouse and field experiments. In field experiments, intercropping and phosphorus fertilization at 100 and 200 kg/fed, respectively, reduced root-rot diseases. Intercropping and phosphorus fertilizer significantly increased yield characteristics, including plant height, number of branches, number of pods per plant, 100-seed weight, and seed yield/fed. The benefits of super phosphate on the vegetative growth parameters might be attributed to its effect on nodulation and yield parameters. Under greenhouse conditions, intercropping the three faba bean cultivars with wheat significantly reduced both pre- and post-emergence of damping-off and root-rot disease caused by fungal pathogens compared to the controls.

Mundt et al. [39] 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. The mixtures reduced the disease severity of yellow rust compared with their component-pure stands by 53%. The four-component mixture improved yellow rust control more than the two-way mixtures. Eyespot severity was reduced through mixing by 13%. The mixtures achieved yields that were relatively greater than the pure stands by 6.2%, 1.7%, 7.1%, and 1.3% in the presence of yellow rust, eyespot, both diseases, and neither disease, respectively. The mixtures showed improved yield stability relative to the pure stands, with the four-component mixture being particularly stable.

8 Role of Intercropping in Weed Control

The presence of weeds is known to have serious effects on a crop growth through competition for light, water, nutrients, location, and/or countermeasures. Research indicates that intercropping is a key to controlling weeds, leading to reduced costs for weed control using pesticides, especially in sustainable agricultural systems with lower inputs. In Egypt, for example, the reduction in maize yield due to weed competition is between 34 and 90% [40, 41]. El-Metwally et al. [42] reported that weeds cause appreciable losses in crop production and deplete nutrients in arable land in Egypt. They showed that weeds associated with maize plants removed 74.7–306.1%, 90–322.2%, and 100.8–317.7% of nitrogen, phosphorous, and potassium, respectively, in weedy check plots more than in weeded treatments.

In this respect, Lawson et al. [43] observed that the intercropping of maize and legumes has generally reduced weed growth and increased the efficiency of photosynthesis for components of intercropping. The cover crops *M. pruriens* var. *cochinchinensis*, *M. pruriens* var. *utilis*, *M. pruriens* var. *nagaland*, and *C. ensiformis* exhibited excellent weed suppression abilities in the range of 79–90% above the weedy check. *Canavalia ensiformis* provided the best weed suppression for maize at a spacing of 40 × 40 cm with weeding once at 5 weeks after sowing.

Productivity shortfalls due to weeds depend on the cultivar of crop, the cultivated species, the number of weeds per unit area, the period of competition, and the stage of crop development. Baumann et al. [44] explained the importance of intercropping in reducing growth and the rate of weed reproduction. The authors recorded a decrease in the total dry matter production rate and weed propagation rate in intercropped agriculture compared to single cultivation in vegetable crops.

Josefina et al. [45] pointed out the role of intercropping with cereal crops in reducing the incidence of *Orobanche crenata* in legume crops, which increased farmers' incomes and increased soil fertility. Furthermore, experiments in Assiut, Egypt [46] intercropped faba bean with lupin, fenugreek, or Egyptian clover on a farm naturally infested with *Orobanche* for two seasons. Intercropping faba bean with either lupin, fenugreek, or Egyptian clover markedly reduced the *Orobanche crenata* Forsk infestation in the faba bean. The number of branches, height of the first pod, number of pods, seed yield, and number and dry weight of *Orobanche* spikes were significantly affected by the intercropping treatments. The intercropping also increased the faba bean seed yield; consequently, the economic return also increased.

A study in Shalakan, Kalubia Governorate, Egypt [47] investigated six intercropping patterns: two pure stand crops, plus intercropped sunflower and soybean at alternating ridges 1:1, 1:2, 2:1, and side by side. The lowest dry weights of grasses were recorded for the 1:1 and 1:2 intercropping patterns. Similarly, at the Mallawi Agriculture Research Center in Middle Egypt, Zohry [48] showed that maize intercropped with cowpea produced the highest grain yield and the lowest values of associated weeds compared to solid maize. This could be attributed to the great competition between maize and/or cowpea plants for light, water, and nutrients. The lowest amounts of weeds (1.61 and 1.61 kg/m^2) were observed when maize was intercropped with cowpea and sequenced by berseem in both seasons. This might be due to the crop sequence causing unfavorable environment for weeds by varying patterns for resources, completion, allelopathic interference, soil disturbance, and mechanical damage (Table 2).

Table 2 Effects of the interactions between preceding crops and cropping systems on weeds in maize intercropped with cowpea during the 2003 and 2004 seasons [48]

Preceding crop	Cropping system	Fresh weight of weeds (kg/m^2)	
		2003	2004
Wheat	Solid maize	2.77	2.74
	Maize + cowpea	1.81	1.74
	Mean	2.29	2.24
Faba bean	Solid maize	2.49	2.58
	Maize + cowpea	1.71	1.64
	Mean	2.10	2.11
Berseem	Solid maize	2.31	2.32
	Maize + cowpea	1.61	1.61
	Mean	1.96	1.97
Onion	Solid maize	2.87	2.81
	Maize + cowpea	1.61	1.65
	Mean	2.24	2.23
Mean	Solid maize	2.61	2.61
	Maize + cowpea	1.69	1.66
LSD 0.05 (preceding crop)		0.13	0.07
LSD 0.05 (cropping system)		0.09	0.07
LSD 0.05 (PXC)		0.18	0.14

LSD least significant difference, $P \times C$ preceding crops X cropping systems

9 Buzz Words

Table 3 summarizes a number of terms are heard often in the context of intercropping and environmental sustainability.

10 Discussion

Intercropping is a multiple-cropping practice in which two or more crops are grown in proximity. The most common goal of intercropping is to produce a greater yield on a given piece of land by making use of resources or ecological processes that would otherwise not be utilized by a single crop. It is particularly essential to have crops that do not compete with each other for physical space, nutrients, water, or sunlight. The intercropping of compatible plants can encourage biodiversity by providing a habitat for a variety of soil organisms that would not be present in a single-crop environment. These organisms may provide crops with valuable nutrients, such as through nitrogen fixation [17].

This chapter has focused on the benefits of intercropping. The positive effects of intercropping include not only the maintenance of soil water and utilization of the available environmental resources, but also facilitation of the activity of microorganisms and nitrogen fixation [11]. This leads to improved physiological and

Table 3 Buzz words for intercropping and environmental sustainability

Buzz word	Quick explanation
Intercropping	The simultaneous cultivation of multiple crop species in a single field to maximize land use and environmental resources, as well as to provide competition to weeds
Sustainable development	Sustainability is the ability to continue a defined behavior indefinitely, expressed as the relationship between people and the ecosystem around it
Biological N_2 fixation	A process by which nitrogen in the earth's atmosphere is converted into ammonia (NH_3) or other molecules available to living organisms
Land equivalent ratio (LER)	The ratio of the area needed under sole cropping to one of intercropping at the same management level to produce an equivalent yield [49]. For example, LER = (Yab/Yaa) + (Yba/Ybb), where Yaa = pure stand yield of crop a (corn), Ybb = pure stand yield of crop b (soybean), Yab = intercrop yield of crop a (corn), and Yba = intercrop yield of crop b (soybean)
T-RFLP technology	Terminal restriction fragment length polymorphism
Push–pull	This system combines the principles of sustainability and biological control in a novel approach to pest management that uses a repellent intercrop and an attractive trap plant
Weed control	The botanical component of pest control attempts to stop weeds, especially noxious or injurious weeds, from competing with desired flora and fauna

biochemical characteristics of the plant rhizosphere, which can lead to increase productivity.

Studies have shown that intercropping is an ideal cropping system. In such a system, light interception, soil moisture, soil temperature, and yield are higher compared to sole crops. Perhaps the most obvious example of this integration is the use of nitrogen between cereals and legumes, where both types are competing for light and soil nitrogen. Planting maize ridges that alternate with soybean or pea that alternates with wheat seem to be well suited to the Egyptian conditions and could be an alternative way to decrease nitrogen inputs by increasing the NUE of cereal crops, thus achieving the highest net return compared to sole crops. Research also indicates that intercropping reduces nitrate washing and reduces groundwater contamination from nitrates [21].

Intercropping species have been the ability to change the biotic and abiotic environments of the root system and further facilitate the uptake of nutritional elements. Clear differences in the composition of bacterial communities have been detected by T-RFLP technology, such as between the plants in the rhizosphere of alfalfa intercropped with the Siberian ray perennial under different treatments. Qualitative differences in the enzyme activity of the rhizosphere soil for both crop fodders also have been reported [25].

Africa faces serious challenges in feeding its population, mainly due to poor yields of cereals, which serve as both staple and cash crops. These challenges are related to insect pests, weeds, poor soil fertility and, more recently, the effects of climate change. A push–pull strategy can help to reduce pest outbreaks by increasing crop predators. This strategy was developed to control stemborers and striga weed in resource-poor maize farming systems. Furthermore, intercropping plays an important role in the biological control of agricultural diseases, such as by intercropping faba bean with canola to avoid the risk of fungal infections [35]. However, additional research is needed in this area.

11 Conclusions

For sustainable agriculture systems in developing countries such as Egypt, research has proven that intercropping increases land use efficiency and the availability of resources such as water, light, and nutrients. In addition, intercropping is a successful method for avoiding pests, encouraging natural enemies, and suppressing weed growth. Therefore, yield advantage can be achieved for the unit area and risks associated with crop production can be reduced.

Recommendations The following approaches are recommended based on the published research:

- Choose suitable intercropping patterns to facilitate and complement environmental resources, such as space, light, and nutrients.
- Select the best adapted crop cultivars to maximize nutrient use efficiency and reduce nitrate leaching.
- Grow promising genotypes in intercropping patterns to reduce the risk of pests, increase productivity and quality, and thus help to overcome the food gap between production and consumption.

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Role of Intercropping in Increasing Sustainable Crop Production and Reducing the Food Gap in Egypt

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Contents

Abstract Intercropping – the growth of two or more crop species simultaneously in the same field area – has been widely practiced worldwide since ancient civilization. Intercropping provides an opportunity to harness and maximize available environmental resources, such as space, light, and nutrients, as well as to improve crop quantity and quality. The current trend in global agriculture is to use agricultural patterns that are highly productive, sustainable, and environmentally friendly. Developing countries such as Egypt have shown considerable interest in intercropping to enhance productivity. In particular, cereal/legume intercropping is commonly used in Africa, as it has shown advantages in yield and nutrient acquisition under stress conditions. Moreover, intercropping provides a method to reduce soil erosion, fix atmospheric nitrogen, reduce the risk of crop failure, and increase land use efficiency.

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1 Introduction

Intercropping – the growth of two or more crop species simultaneously in the same field area – is a method to increase biodiversity in agro-ecosystems. Results from intercropping studies indicate that crop diversity may improve the quality of an ecosystem. Greater species richness may be associated with nutrient cycling characteristics that often can regulate soil fertility, limit nutrient leaching losses, and significantly reduce the negative impacts of pests, including weeds.

The importance of sustainable intensification technologies in the production of the world's key food security crops – maize, rice, and wheat – has been highlighted recently. In so-called save-and-grow farming systems, cereals are regarded not as monocultures but as components of intercropping farming systems [1]. For cereals such as maize and wheat, intercropping has improved yields and soil fertility. Intercropping maize and soybean is an important agricultural system for increasing the productivity of Egyptian farms without any additional costs; the morphological and physiological differences between the two crops provide mutual benefits [2]. Furthermore, intercropping legumes with maize is a beneficial production technique with low risks [3].

2 Types of Intercropping Systems

2.1 Intercropping Legumes with Cereals

Egypt suffers from a shortfall in the production of grain and oil crops, which has led to a widening gap between production and consumption due to population growth. The government has aimed to increase the productivity of these crops by introducing new varieties, using modern farming methods, and cultivating new land. Intercropping can help to solve this problem.

2.1.1 Soybean and Maize

The philosophy of intercropping depends on exploiting available environmental resources and increasing the yield per unit area. Thus, intercropping legumes with maize provides many benefits for the soil and associated cereal crops, such as maize. This system reduces the depletion of elements from the soil more than maize alone [4]. When intercropping soybeans with maize, yield and other attributes of both crops may be examined. Intercropped soybeans may use one of the following series of replacements: 50% maize/50% soybean, 75% maize/25% soybean, or 25% maize/75% soybean.

Al Kaddoussi et al. [5] studied a maize/soybean intercropping system over two seasons (2000 and 2001). The results of this investigation were as follows:

1. The competition between intercropped maize and soybean was mainly due to interspecific competition for plant height and grain yield (Ardab/fad.) in both seasons.
2. Intraspecific competition was the main factor in soybean seed yield (kg/fad.) in both seasons, indicating the competitive ability of this trait.
3. Competition indicators showed that rebound value (*a*) and response (*r*) had different signals for plant height in both seasons, thus indicating the importance of interspecific competition. The values of (*a*) and (*r*) had the same signal for yield/fad. in both seasons of the experiment, which shows the importance of intraspecific competition in explaining the differences between maize and soybean yield amounts.
4. Intercropping both components in ridges into specific combinations resulted in a higher biological yield than solid planting.

These results are important for plant breeders who wish to implement an effective breeding program and select the best intercropping combinations to get high yields for both components (maize and soybean) (Table 1).

In Eqypt, El-Naggar [6] studied the effects of intercropping with farmyard manure (FYM; 0, 20, and 40 m^3/fad) and nitrogen fertilization (0, 45, 90, and 120 kg/fad) on the relative photosynthetic potential (RPP) and migration coefficient (MC) of maize (TWC 324) and soybean (Giza 22) grain and seeds (Fig. 1). Growing three ridges of maize in alternation with three ridges of soybean resulted in higher RPP for grains and seeds than solid planting due to the competition of the two component crops. However, the average decrease in RPP grains was of higher magnitude in maize (53.9%) than in soybean (52.6%) indicating that the former was imposed, also, under more interspecies competition with the latter (Table 2). However, solid-seeded soybean had much higher MC than intercropped soybean. Likewise, solid-seeded maize and soybean had greater grain and seed yields/fad than intercropped plants. The percentage decrease in the seed yield due to intercropping was greater for soybean (14.02%) than maize grain yield (13.28%). These results indicate that soybean plants may have high interspecific competition with maize (Table 3).

2.1.2 Common Bean and Maize

Common bean (*Phaseolus vulgaris* L.) is a widely cultivated crop with good nutritional value, containing a high percentage of protein in its seeds and a high proportion of fiber in its vegetative yield. Intercropping common bean with maize is a successful intercropping system in many countries. In a study of intercropping efficiency and yields of maize and common bean in Turkey, the highest land equivalent ratios (LERs) of seed yield were found for alternating rows of maize and common bean (1.39), a 2:1 planting ratio of maize and common bean (1.21), and the simultaneous sowing of maize and common bean (1.21), respectively. Seed yield decreased for intercropped bean and maize by 57.47 and 25.77%, respectively,

Table 1 Estimates of regression indicators *a*, bm, and bd and competition indicators *I*, *r*, *a,* and *C* for plant height and yield in a maize/soybean intercropping system [5]

Parameters	2000 season		2001 season	
	Maize	Soybean	Maize	Soybean
Plant height				
$a \pm$ S.E	260 ± 3.647	85.966 ± 3.647	258.396 ± 1.888	86.242 ± 1.888
bm ± S.E	−0.083 ± 0.083	−0.058 ± 0.083	−0.012 ± 0.043	0.043 ± 0.043
bd ± S.E	−0.042 ± 0.083	0.126 ± 0.083	0.025 ± 0.043	−0.010 ± 0.043
Competitive values				
	Cmm = −bm 0.083	Css = −bm 0.058	Cmm = −bm 0.012	Css = −bm −0.043
	Cms = bd−bm 0.041	Csm = bd−bm 0.184	Cms = bd−bm 0.037	Csm = bd−bm −0.054
Competition parameters (*C*, *a*, *r*, and *i*)				
C	0.092		−0.012	
a	0.042		−0.008	
r	−0.029		0.037	
i	−0.021		−0.003	
$a + r$	0.012		0.028	
$r -$ a	−0.071		0.046	
Yield				
$a \pm$ S.E	28.790 ± 20.448	640.530 ± 20.488	35.470 ± 12.124	626.802 ± 12.124
bm ± S.E	−0.004 ± 0.468	−1.685 ± 0.468	0.030 ± 0.277	−1.179 ± 0.277
bd ± S.E	−0.049 ± 0.468	−0.925 ± 0.468	0.022 ± 0.277	−0.701 ± 0.277
Competitive values				
	Cmm = −bm 0.004	Css = − bm 1.685	Cmm = − bm −0.030	Css = −bm 1.179
	Cms = bd−bm −0.044	Csm = bd−bm 0.759	Cms = bd−bm −0.007	Csm = bd−bm 0.478
Competition parameters (*C*, *a*, *r*, and *i*)				
C	0.601		0.405	
a	−0.219		−0.181	
r	−0.621		−0.423	
i	0.243		0.169	
$a + r$	−0.840		−0.604	
$r - a$	−0.401		−0.242	

Fad = 4200 m^2; *a* difference between the competition pressure exerted by the two components, i.e. maize and soybean; *bm* intra competition; *bd* inter competition; *S.E* standard error; *C* competition interaction within and between maize and soybean; *r* difference between the two crops in the magnitude of their response to any given competitive pressure; *i* interaction between *a* and *r*; *Cmm* intra competition (within maize); *Cms* inter competition exerted by maize on soybean; *Css* intra competition (within soybean)

over 2 years. Overall, alternate row planting, a 2:1 planting pattern of maize and common bean, and simultaneous planting of the component crops were recommended due to their simplicity, easy applicability, and usability in most ordinary farming conditions [7].

Fig. 1 Intercropping maize and soybean (3:3 pattern) [6]

In a study of the response of maize and common bean to the population density of component crops in Ethiopia, no significant differences were found between sole crops and intercropped maize with regard to crop phenology, days to physiological maturity, growth parameters, yield, and yield components. Sole common bean was significantly superior to intercropping with regard to leaf area and leaf area index. Intercropping maize with common bean under the highest plant population (93,750 plants/ha) resulted in the greatest yield and economic advantages (42% and 36898.2 Ebirr, respectively) [8].

2.1.3 Cowpea/Lablab and Maize

The effects of intercropping maize/cowpea and lablab on crop yield and sheep growing performance have been studied in Ethiopia. Solid cropping of all components resulted in 50% less days to flowering and 90% physiological maturity. This result indicates that the shading effect of taller maize plants causes a delay in flowering and maturity for intercropped cowpea and lablab. The plant height of sole crops was also greater than the height of intercropped plants for maize-lablab and maize-cowpea systems. Furthermore, the aboveground biomass, biological yield per hectare, grain yield per hectare of maize, and forage grain yields of cowpea and lablab decreased due to intercropping. This might be attributed to competition as a result of the fast growth, climbing, shading, and suppression from the legumes (i.e., cowpea and lablab). However, the number of nodules per plant was significantly higher under intercropping compared to solid planting, which may be due to the

Table 2 Relative photosynthetic potential for grain yield per plant as affected by intercropping, farmyard manure, and nitrogen fertilization in two seasons [6]

Main effects and interactions	Maize			Soybean		
	2009 season	2010 season	Both seasons	2009 season	2010 season	Both seasons
Planting patterns (P):						
P1: Solid planting	80.52	70.89	75.70	15.80	15.00	15.47
P2: Intercropping	36.79	31.87	34.83	7.32	7.35	7.34
F-test	**	**	**	**	**	**
FYM levels (F), m³/fad.:						
F1: Without	57.23	48.54 b	53.63 b	10.84 b	11.54	11.29 b
F2: 20	59.20	41.73 c	55.47 ab	10.88 b	11.11	10.99 b
F3: 40	59.53	53.88 a	56.70 a	12.96 a	10.89	11.93 a
F-test	N.S	**	**	**	N.S	**
Nitrogen fertilization (N), kg N/fad.:						
N1: Without	56.06 d	50.23	53.15 c	11.23 c	10.15 d	10.82 b
N2: 45	58.84 c	52.29	55.57 b	10.86 d	10.52 cd	10.69 b
N3: 90	59.35 b	52.09	55.72 ab	12.69 a	11.18 bc	11.94 a
N4: 135	60.36 a	50.92	56.64 a	11.46 bc	12.87 a	12.17 a
F-test	**	N.S	**	**	**	**
Interaction:						
P × F	N.S	N.S	**	N.S	N.S	**
P × N	*	N.S	**	N.S	**	**
F × N	N.S	N.S	N.S	N.S	N.S	**

N.S not significant. *Significant at 0.05 level. **Significant at 0.01 level. *FYM* farmyard manure, Fad. = 4,200 m^2. "a–d" provided by statistical analysis where, the treatments with similar letters, there is no significant difference between them, while the treatments with different letters there is a significant difference between them

crop competition stimulating nodulation. Intercropping maize with cowpea resulted in the highest LER (1.71), followed by intercropping maize with lablab (1.65). These results indicate that intercropping is advantageous to sole cropping in many instances, possibly because of the mutual complementary effects of component crops [9, 10].

2.1.4 Mung Bean and Maize

Intercropping maize with mung bean or urad bean provides many benefits for the soil and associated maize. Mung bean is one of the most important legumes. Its seeds have high contents of protein and lysine, so it is added to human foods. Furthermore, its leaves, hay, and seed pods are used in animal feed.

In the intercropping of maize and legumes, the soil surface was shown to retain more moisture during a drought period (6–8 days) than a maize crop alone. As well, the intercropped plants supply nitrogen to the soil through nitrogen biosynthesis fixation [11, 12]. The effects of different intercropping patterns have been studied,

Table 3 Maize grain and soybean seed yields as affected by intercropping, farmyard manure, and nitrogen fertilization in two seasons [6]

Main effects and interactions	Grain yield/fad. (ton)			Seed yield/fad. (kg)		
	2009 season	2010 season	Both seasons	2009 season	2010 season	Both seasons
Planting patterns (P):						
P1: Solid planting	3.67	3.69	3.68	820.35	835.85	828.35
P2: Intercropping	2.97	3.06	3.01	710.37	714.04	712.20
F-test	*	*	**	*	*	**
FYM levels (F): (m^3/fad.):						
F1: Without	2.96 c	2.95 c	2.95 b	737.54	737.26 c	737.77 c
F2: 20	3.42 b	3.44 b	3.43 a	756.81	765.97 b	761.39 b
F3: 40	3.58 a	3.74 a	3.44 a	801.73	821.61 a	811.67 a
F-test	**	**	**	N.S	**	**
N-fertilization N: (kg N/fad.):						
N1: Without	2.67 d	2.68 d	2.67 d	682.58 d	671.66 d	677.12 d
N2: 45	3.09 c	3.18 c	3.13 c	741.97 c	745.79 c	743.88 c
N3: 90	3.59 b	3.57 b	3.58 b	807.88 b	826.62 b	817.75 b
N4: 135	3.92 a	4.07 a	3.99 a	829.01 a	855.70 a	842.35 a
F-test	**	**	**	**	**	**
Interaction:						
P × F	N.S	N.S	N.S	N.S	N.S	N.S
P × N	N.S	N.S	N.S	N.S	N.S	N.S
F × N	N.S	N.S	N.S	N.S	N.S	N.S

N.S not significant. *Significant at 0.05 level. **Significant at 0.01 level. *FYM* farmyard manure; Fad. = 4,200 m^2. "a–d" provided by statistical analysis where, the treatments with similar letters, there is no significant difference between them, while the treatments with different letters there is a significant difference between them

as follows: mung bean alone, maize + one row of mung bean simultaneously seeded, maize + two rows of mung bean simultaneously seeded, maize + one row of mung bean seeded 3 weeks later, and maize + two rows of mung bean seeded 3 weeks later. Intercropped treatments had significant effects on the number of nodules per plant, the dry weight of nodules, the number of pods per plant, the number of seeds per pod, 1,000-seed weight, seed yield, and biological yield. However, there were no significant effects on the fresh and dry biomass of weeds [13].

The greatest number of nodules per plant (9.87), dry weight of nodules (2.10 g), pods per plant (17.37), seeds per pod (4.23), 1,000-seed weight (39.33 g), biological yield (1,654 kg/ha), and seed yield (525 kg/ha) of mung bean were obtained for sole mung bean compared with mung bean intercropped with maize in all combinations. This may be due to better availability of growth factors from the lack of interspecies competition in sole cropping. The seed yield of mung bean decreased in intercropped plots, which may be due to the shading effect of maize due to variations in plant architecture, in addition to the competition between the two components for water and nitrogen [13]. Similarly, another study [14] intercropping paired rows of maize + two rows of chickpea would agronomic ally achievable and economically profitable (i.e., maize equivalent yield, LER, relative yield, gross return and net return).

2.2 Intercropping Oil-Legumes with Cereals

2.2.1 Groundnut and Maize

In Egypt, Sherif et al. [15] studied the effects of four planting densities (one plant or two plants per hill 50 or 100 cm apart) and three planting dates for maize (June 1, 10, and 20). The authors found that increasing maize spacing with one plant per hill increased maize yield, plant height, and ear height in most cases, except for plants that carried two ears. Yield and most of studied characteristics decreased by delaying the planting date of maize from unfavorable growth conditions. Furthermore, decreasing the planting density of maize and delaying its planting date led to an increase in groundnut yield and its attributes by decreasing interspecific competition. The results indicate that delaying the planting date of maize increased land use efficiency and decreased the competition ratio. Dense maize plants (50 cm apart at two plants per hill) increased land use efficiency and the relative crowding coefficient.

In Ghana, Dwomon and Quainoo [16] investigated different intercropping ratios of maize alternated with groundnut, sole maize, and sole groundnut. The authors reported better grain and seed yields for the sole crops of maize and groundnut, with a 3:3 ratio (three rows of maize alternating with three rows of groundnut) resulting in the lowest yield. The sole crops had higher LERs than the 3:1, 3:2, and 3:3 spatial arrangements, which had LER values of 0.91, 0.92, and 0.84, respectively. However, the 3:1 spatial arrangement (three rows of maize alternating with one row of groundnut) produced the highest monetary advantages (MA) values of GH¢ 9631, whereas the 3:3 spatial arrangement produced the lowest MA values of GH¢ 855. Moreover, the intercropping advantages (IAs) for the 3:1, 3:2, and 3:3 arrangements were reported to be 1.29, 0.57, and 0.26, respectively. Thus, three rows of maize alternating with one row of groundnut proved to be the most beneficial arrangement.

2.3 Intercropping Legumes with Oil Crops

2.3.1 Faba Bean and Canola

Egypt has limited areas to cultivate oil crops, particularly in Nile Delta fertile lands, and insufficient oil production for domestic consumption. The cultivation of promising crops, such as canola, through crop rotation and intercropping systems may help to increase land use efficiency and reduce the gap between production and consumption.

Selim et al. [17] studied the effects of intercropping faba bean with canola in Egypt in three patterns (two faba bean/two canola ridges, four faba bean/two canola ridges, and two faba bean/four canola ridges) at 50%, 75%, and 100% of the recommended population density. Increasing the proportion of faba bean to one-half or one-third of the intercropped unit increased its seed yield/fad. An intercropping ratio of 4:2 resulted in the highest seed yield for faba bean; however, a 2:4 ratio produced the highest yield advantage for the associated canola. Moreover, there were no significant effects of intercropping on canola oil content, which may be due to the lack of intraspecies competition. Decreasing plant populations of both components had no significant effects on the seed yield of faba bean per plant, faba bean per fad, or canola oil content. This study demonstrated a high compensation relationship between the component crops, especially in the first season at an intercropping ratio of 2:4. The other two patterns showed a mutual cooperation effect for the component crops on seed yield/fad. An intercropping ratio of 4:2 increased the faba bean seed index at 75% of the recommended planting density for associated canola. Land use efficiency increased under an intercropping pattern of 4:2 with a 10–29% advantage [area time equivalency ratio (ATER) = 1.10–1.29]. Also, using plant populations of 105,000 and 52,500 plants/fad of canola increased the benefit by 11% and 17% during both seasons, respectively. Intercropping faba bean with canola also reduced the risk of fungi infection, which affect solid faba bean plants in wet seasons.

A study in Iran investigated the biological effects of canola-faba bean intercropping compared with solid planting on the density and diversity of weeds. Experimental treatments included the following: (1) canola (*Brassica napus* L. var. haylo) and faba bean (local cultivar); (2) plant densities of 0, 20, and 40 plants/m^2 for canola and 0, 20, 40, and 60 plants/m^2 for faba bean in accordance with an additive form mixed culture system, respectively. Increasing the faba bean density caused a decline in the dry weight of weeds. Because the diversity of weeds had been clearly affected, it may be possible to control weeds effectively with an intercropping system. The lowest dry weight of weeds was observed for 20 and 40 canola plants/m^2 and 60 faba bean plants/m^2, at 5.64 g/m^2 and 6.96 g/m^2, respectively [18].

2.4 Intercropping Legumes with Long-Duration Crops

2.4.1 Faba Bean and Cotton

Intercropping cotton with faba bean is a new trend in Egyptian cropping systems, which may help to increase the total productivity per unit area. When cultivating faba bean in a cotton crop rotation, several faba bean early maturity varieties may be used, such as Giza 706, Sakha 1, Giza 40, and Wady 1. Ideally, they should be planted in the second half of October to mature and harvest in the second half of March in middle and upper Egypt or the first week of April in lower Egypt. The cotton could be planted on its appropriate planting date on faba bean ridges.

Saleh et al. [19] studied the effects of previous crops (maize, sunflower, and soybean) and intercropping cotton with faba bean under three plant spacings (10, 20, and 30 cm) on the growth, yield, and yield components of both crops. The experimental design used split-split plots in three replicates. The previous crops significantly influenced faba bean plant height, pod weight/plant, and seed yield but had no significant effects on cotton yield or its components. Increasing the hill space from 10 to 30 cm improved all investigated faba bean traits except for plant height and yield/fad (which increased by diminishing the plant spacing to 10 cm); cotton traits were not affected. The intercropping had significant effects on faba bean pod numbers per plant and seed yield/fad, although cotton yield per plant, cotton yield per fad, percentage of lint, and yield components were not affected. A hill space of 10 cm was superior to 20 and 30 cm in both seasons and their combined analyses. Furthermore, the total income was higher when cotton was planted in relay intercropping with faba bean after maize than for solid cotton. The net income of intercropping cotton with faba bean also increased more than for sole crops.

Intercropping cotton with some winter crops has also been investigated and compared with sequential solid plantings of these crops with regard to productivity, LER, and net returns. The Egyptian cotton cultivars Giza 86 and Giza 90 were intercropped with wheat (Sakha 93), faba bean (Giza 3), and Egyptian clover (Helaly). The results showed that solid planting of faba bean in high density resulted in the highest seed yield. LER decreased significantly (by 10%) by intercropping cotton with faba bean compared with a sequential double cropping system. In addition, the results indicate that the seed yield of faba bean decreased significantly under intercropping cultures compared with solid cropping. This may be due to interspecies competition between cotton and faba bean plants for light, nutrients, and water [20].

2.5 *Intercropping Cereals with Long-Duration Crops*

2.5.1 Cotton and Wheat

Relay intercropping of cotton with wheat helps to redevelop cotton crop rotations, expand cultivated areas of wheat and cotton, and maximize crop intensification and return income per unit area of land compared to sole cotton. This approach helps to avoid infestation with spiny bollworm *Earias insulana* [Boisd] or pink bollworm *Pectinophora gossypiella* because cotton can be cultivated earlier. Furthermore, the risk of mole cricket *Gryllotalpa gryllotalpa*, black cutworm *Agrotis ipsilon*, aphids *Aphis gossypii,* and thrips *Thrips tabaci* decreases because the amount of water used to irrigate both crops can be reduced [21].

Abd El-Hady and El-Khatib [22] studied the effects of intercropping Egyptian cotton cultivar (Giza 80) with wheat (Sids 4) and seedling cotton after wheat harvest on growth, yield, and yield components. Treatments were as follows: 67% cotton with 33% wheat on ridges at 120 cm for 70,000 plants/fad (T_1); 67% cotton with 33% wheat on ridges at 103 cm for 65,213 plants/fad (T_2); 69% cotton with 31% wheat for 62,222 plants/fad (T_3); 72% cotton with 28% wheat for 60,000 plants/fad (T_4); solid cotton at 64,600 plants/fad (T_5); solid wheat in rows 10 cm apart (T_6); and seedling cotton at 64,600 plants/fad after wheat harvest (T_7). The sowing dates of wheat were November 27 and 23. Cotton was planted on April 18 and 20 April in both seasons. The highest seed cotton yield/fad and yield components resulted from sole cropping followed by T_3; otherwise, seedling cotton decreased the yield and its components because of damage to the cotton roots as a result of the seedling method. Quality traits were not affected by intercropping treatments. The highest wheat grain and straw yields per fad were produced from the solid cropping of wheat, followed by intercropping treatments. Intercropping cotton and wheat led to an increase in land use efficiency, which indicates the success of this intercropping system.

In the same regard, two field experiments were conducted at a farm of the Faculty of Agriculture, Zagazig University, to investigate the effects of intercropping Egyptian cotton cultivar (Giza 85) with wheat cv. (Gemmeiza 3) on the crops' yields and yield components. Sole and intercropped cotton were planted at three planting dates (5 March, 25 March, and 15 April), as well as on 15 May after sole wheat harvest, under three nitrogen fertilizer levels (40, 60, and 80 kg N/fad). Intercropping cotton with wheat on 25 March resulted in the highest wheat yield and yield components. Planting cotton on the same date – whether solid or intercropped with wheat – produced the highest cotton yield and yield components. Income also increased by intercropping cotton and wheat on 25 March compared with planting cotton after wheat. Intercropping cotton and wheat had also positive effects on land use efficiency: 82%, 93%, and 213% in the first season and 81%, 96%, and 211% in the second season. Intercropping cotton in relay with wheat on 15 March with 60 kg N/fad lead to an increase in the wheat cultivated area, which helps to reduce the gap between production and consumption. In addition, the cotton cultivated area was expanded without any effects on its productivity and quality, with greater crop intensification and return income per unit area compared to sole cropping [23].

2.6 Intercropping Legumes, Oil, or Vegetables with Sugar Crops

2.6.1 Faba Bean and Sugar Cane

Sugar cane is a long-duration crop. Spaces between its rows may remain empty for 3–4 months, which provides a good opportunity to intercrop one or two short-duration crops to take advantage of complementary growth resources and improve the productivity of sugar cane. Intercropping sugar cane with legumes can maximize productivity per unit area. Generally, intercropping systems of crops with sugar cane aim to increase productivity and return income per unit area, as well as reduce water consumption by using it to irrigate both crops. Climatic and soil factors may favor the cultivation of certain economical oil crops, such as sesame, soybean, and sunflower, to meet shortages of the required quantity of oil. Legumes and vegetables can also be rotated with sugar cane to utilizing land during periods of reduced sugar cane growth.

The most important plants that have been intercropped with autumn sugar cane with positive effects and profitable income were faba bean, onion, tomato, sugar beet, lentil, and cucumber. When intercropping with sugar cane, autumn sugar cane should be planted earlier in September to boost emergence, hoeing twice before intercropping the other plant and applying the first dose of nitrogen fertilizer. The associated plant should be intercropped after the second hoeing at the end of October or the beginning of November. The field should be irrigated after harvesting the associated crop. When it dries, the plant should be hoeing for a third time to set up the ridges. The second dose of nitrogen fertilizer should then be added and all other agricultural practices continued until harvest.

In Egypt, Farghaly [24] studied the effects of intercropping faba bean with sugar cane on yield and quality under three planting densities of faba bean. The experiment included five treatments as follows: a sole crop of each component, sugar cane + one row of faba bean, sugar cane + two rows of faba bean, and sugar cane + three rows of faba bean. The experimental design used randomized blocks in four replicates. The intercropping treatments had a significant effect on sugar cane and faba bean yields, especially under density (i.e., three rows of faba bean). Sugar cane and faba bean yields decreased by 9% and 41%, respectively, from intercropping compared with their yields from sole cropping. The total soluble solid (TSS), sucrose, and purity percentages responded significantly to intercropping treatments more than sole cropping. Land use efficiency increased by 45–62.5% when faba bean was intercropped with sugar cane. The relative crowding coefficient value indicated a preference for intercropping faba bean and sugar cane. The aggressivity index showed that sugar cane was dominate to faba bean under all intercropping treatments. Accordingly, the study concluded that a faba bean/autumn sugar cane system was successful and profitable, especially using a moderate density pattern (i.e., two rows of faba bean).

2.6.2 Oil/Legume/Maize and Sugar Cane

Intercropping soybean, sunflower, sesame, mung bean, cucumber, and tomato with spring sugar cane or during the third tilling stage is an ideal use of land that also increases income for farmers. Sugar cane/oil and vegetable crop systems maximize the productivity per unit area. A few factors should be taken into account when intercropping with sugar cane to increase the productivity per unit area in Egypt: (1) complete the planting of sugar cane in the period between mid-February to mid-April; (2) cultivate the associated crop with sugar cane planting and irrigate the soil to reach the appropriate moisture; and (3) complete the fertilization of sugar cane in the beginning of July.

Abou-Kresha [25] studied the effects of intercropping on the yields of main stem and third ratoon sugar cane by intercropping it with soybean, sesame, sunflower, and maize in three patterns: intercropping on all ridges, intercropping two of three ridges, and intercropping two of four ridges in a split-plot design. The yields of sugar cane and the other component crops decreased under intercropping in comparison with sole crops. The yield of intercropped sugar cane with soybean or sesame was greater than with sunflower or maize. TSS, sugar, and purity percentages were not affected by intercropping in main stem sugar cane but changed in the third ratoon. Land use efficiency increased by intercropping main stem sugar cane and third ratoon; it was high for sugar cane/soybean and low for sugar cane/sunflower. The interspecies competition between sugar cane plants, sunflowers, and maize was higher than that between sugar cane plants, soybeans, and sesame. The relative crowding coefficient indicated a preference for intercropping with soybeans. The aggressivity index showed that sugar cane was dominant under all treatments. Finally, intercropping in the third ratoon appeared to be profitable, as was the case for main stem sugar cane in Egypt.

Another study examined the influence of the intercropping patterns of Egyptian sunflower cv. (Sakha 53) in the following arrangements: one ridge with 30 cm between hills, two ridges with 60 cm between hills, and three ridges with 90 cm between hills. The planting dates included directly after sugar cane harvest and 1 month after the first date. The sunflower planting date significantly affected stem diameter, head diameter, head weight, seed weight/head and seed yield/fad in both seasons. Plant height was also affected in the first season when sunflower was planted directly after sugar cane harvest. Seed yield increased by 146.81% and 40.64% compared to planting 1 month after sugar cane harvest; this may be due to the increase in head diameter, head weight, and seed weight/head. Land use efficiency increased with intercropping sunflower/sugar cane by 1.81 and 1.72 for intercropping two rows of sunflower with 60 cm between hills and one row of sunflower with 30 cm between hills, respectively. Intercropping sunflower on one ridge with 30 cm between hills reduced stalk rot for the first planting date. The sunflower planting date had no significant effects on sugar cane yield or yield attributes in either season of the study. Maximum plant height, stem diameter, number of tillers/m^2, cane yield/fad, and sugar yield/fad were affected by planting sunflower 1 month after sugar cane harvest. The intercropping patterns had no significant effects on sugar cane yield or yield attributes in either seasons, but they did affect plant height in the first season and cane yield/fad in the second season. Interactions between planting dates and intercropping patterns had significant effects on stem diameter, stem weight, number of stems/m^2, and sugar yield in the second season. The highest return income came from intercropping two rows of sunflower with 60 cm between hills directly after the first season's sugar cane harvest and from one row of sunflowers with 30 cm between hills in the second season [26].

In China, researchers studied the effects of intercropping sugar cane and groundnut on weed growth in sugar cane fields using four treatments: ratoon, groundnut sole cropping, sugar cane sole cropping, and intercropping sugar cane with groundnut. The authors concluded that weed density and weed types were reduced under intercropping by 44.4% and 34.0% compared with sole groundnut and by 37.5% and 22.7% compared with sole sugar cane, respectively. The weed yield also decreased under intercropping by 33.7%, 40.9%, and 55.8% compared with ratoon, sole groundnut, and sole sugar cane, respectively [27].

2.6.3 Onion/Potato-Sesame and Sugar Cane

In a study that intercropped sugar cane with onion and potatoes followed by sesame, intercropping sugar cane + potatoes + onion was the best combination for improving land use efficiency [28]. Furthermore, intercropping sugar cane with potato followed by sesame produced the highest yield of sugar cane, potato, and sesame, as well as the greatest number of tillers, stem diameter, and stem weight per unit area. However, intercropping sugar cane with onion followed by sesame provided the highest return income. Overall, intercropping systems of sugar cane achieved the best agricultural and economic performance versus sole cropping [29].

2.6.4 Faba Bean and Sugar Beet

Intercropping faba bean with sugar beet or trees was shown to increase faba bean yield by 30% and 59.5%, respectively, in comparison to farmers' fields [30]. Hussein and El-Deeb [31] studied the effect of intercropping faba bean, chickpea, and lentil/sugar beet on yield and return income in two experiments that were carried out in El-Minia Governorate, Egypt. The authors reported that intercropping faba bean at a rate of 6–8 plants/m^2 with sugar beet resulted in the highest seed yield (0.629–0.734 ton/ha, respectively). Also, intercropping chickpea at a rate of 17 plants/m^2 produced 0.645 ton/ha, whereas intercropping lentil at a rate of 175 plants/m^2 resulted in a seed yield of 0.223 ton/ha. Intercropping faba bean at a rate of 4 plants/m^2 with sugar beet increased the return income compared with sole sugar beet.

In Egypt, El-Shamy et al. [32] studied the mineral nitrogen levels, biofertilizer sources, and plant density of a faba bean/sugar beet intercropping system. Intercropping sugar beet with faba bean in a 30-cm planting distance with the application of 72 kg of nitrogen in combination with Rizobacterien resulted in the greatest root yield (25.36), seed yield (1.09 ton/fad), protein percentage (21.65%), LER (1.170), and total net income (17,669.61 L.E/fad) for sugar beet and faba bean. A narrow distance of faba bean (10 cm) resulted in the highest root sugar percentage (15.13%); however, its interaction with 36 kg of mineral nitrogen along with Cerealine or Rizobacterien (either alone or combined) resulted in the lowest values of the other characteristics in both seasons of this study.

2.7 Intercropping Cereals with Sugar Crops

2.7.1 Wheat and Sugar Beet

Many field experiments were carried out in Gemmeiza, Gharbia Governorate-Egypt, through two seasons (2009/2010 and 2010/2011) to study the effects of wheat and sugar beet intercropping. The greatest root length, thickness, fresh weight per plant, and root yield/fad were obtained by intercropping wheat with sugar beet on the second terrace. Sugar beet quality characteristics were significantly better with relay intercropping of wheat 42 days after planting sugar beet. Land use efficiency (1.123 and 1.032), relative crowding coefficient (12.99 and 5.39), and total return income (9,843.43 and 12,516.14 L.E) were obtained by sowing wheat on the top of the second terrace of sugar beet in the first season and on all terraces in the second season. Thus, the best results were obtained by intercropping wheat 42 days after the sugar beet planting date on the top of the second terrace [33].

An intercropping system of wheat with sugar beet significantly reduced all traits of sugar beet as compared with the sole crop in both seasons. The intercropping system and sowing date significantly affected the yield and yield components of wheat in both seasons, except for spike length in the first season and number of spikelets in the second season, respectively. Intercropping wheat with sugar beet on 42 days after planting sugar beet in both seasons obtained the highest values. The interactions between the intercropping system and sowing dates of wheat had significant effects on all characteristics of sugar beet, except for yield (t/fad.) in both seasons; however, all characteristics of wheat were not significant in both seasons, except for plant height, number of spikes/m^2, number of grains per spike, and grain yield/fad in both seasons. In addition, TSS and sucrose in sugar beet had the highest values when the wheat was cropped on the other side of the second ridge of sugar beet and after 42 days from sowing sugar beet in both seasons. Thus, the greatest values of LER were 1.306 and 1.253 in the first and second seasons, respectively. Intercropping 25% (12.5 kg seed/fed) with a pure stand of wheat (50 kg/fed) resulted in the highest gross return/fad [33].

3 Conclusions

Egypt suffers from a shortage in grain and oil crop production, which is increasing the gap between food production and consumption levels. The productivity of these crops could increase by introducing new varieties, expanding cultivation to new land, and implementing modern farming methods. As demonstrated in this chapter, intercropping can increase land use efficiency and help to solve this problem. An intercropping system is generally successful under Egyptian conditions, with regard to both soil and climate.

A symbiotic relationship between legumes and root nodule bacteria (*Rhizobium* sp.) helps to improve soil properties through nitrogen fixation in soil. As an associated crop, maize can use the fixed nitrogen and thus could reduce the need for manufactured fertilizers, which can pollute the soil and its microorganisms. Intercropping oil crops with maize (as one of the grain crops) or with legumes also has many benefits, such as an improved crop advantage and increased use efficiency of the cultivated area. Furthermore, as feed for sheep, a mixture of basal hay + cow pea or lablab from an intercropping system of cow pea and lablab/maize has been shown to improve sheep growth performance and increase net profits [9, 10].

Using grain and legume crops in intercropping systems with cotton, sugar cane, and sugar beet helps to increase the productivity of a unit area and improve the production of these crops. This may be a result of nitrogen fixation by the legumes and free space between the ridges of cotton, cane, or beet. This benefits are especially noticed with the multiplicity of components involved in specific intercropping systems, such as oil crops, legumes, maize, and/or onions with sugar cane.

4 Recommendations

Based on the information presented in this chapter, the following recommendations can be made:

– Intercropping should be used to increase grain and oil crop production, thus reducing the gap between food production and consumption.
– The use of intercropping systems should be expanded to include grain and legume crops, such as intercropping maize with common bean, soybean, or groundnut (as oil-legume crops), as well as with cow pea and/or lablab (as forage-legume crops).
– Land use efficiency should be optimized for fields of long-duration crops such as cotton, sugar cane, and sugar beet. This can be achieved by intercropping grain crops such as wheat, legumes such as faba bean, and vegetable crops such as potatoes and onions.

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Sustainable Cultivation of Rice in Egypt

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Abstract Rice (*Oryza sativa* L.) is the staple food for more than half of the human population, and as such it plays a key role in ensuring food security all over the world. Rice crop plays a significant role in Egypt, for sustaining the food self-sufficiency and for export. Rice is considered the most popular and important field crop in Egypt for several reasons: as a staple food for more than 50% of Egyptians, as an important exporting crop, as a land reclamation crop for improving the productivity of the saline soils widely spread in Nile Delta and coastal area, low cultivation coasts in comparison to other summer field crops, and finally it is a social crop in which every person of the farm families could find work in rice fields and gain money during the growing season. Rice research started in Egypt 100 years ago and had very advanced achievements during the last thirty years after the establishment of the Rice Research and Training Center (RRTC) at Sakha, Kafr Elsheikh. After the release of the newly developed Egyptian rice varieties, the national average increased to about 10.00 tons ha^{-1} which is considered one of the highest worldwide. Further increase in rice production through increased yield per unit area is needed to meet the increasing demand of growing population in spite of limited resource of arable lands, irrigation water, and fertilizers.

Keywords Achievements and challenges, Rice, Sustainable cultivation in Egypt, Varietal improvement

1 Introduction

Rice (*Oryza sativa* L.) is one of the most important food crops all over the world, since it is considered as the stable food and energy source for more than half of the global population [1], especially in developing countries. Rice ranks second in world production after maize [2].

In Egypt, rice is rated first among the important field crops. This importance comes, for instance, because of its low cultivation costs in comparison with other field crops such as maize and cottons. Another reason is rice successful cultivation in northern Egyptian lands, where the composition of the soil is heavy clay with high levels of salinity, which is not appropriate for many other crops. So, rice could be used also as a land reclamation crop to improve the productivity of poor and new lands. In addition, rice is stable food for about 50% of Egyptians, especially in the Nile Delta and northern Egypt [3]. Moreover, rice is an important exporting crop and could be important source of foreign currency. Finally, rice is a social crop that enables many workers to gain money during its growing season. For these reasons, great efforts have been done to develop high-yielding and pest resistant modern Egyptian rice varieties with high grain quality. As a result of these efforts, Egypt has now many highly stable yielding varieties which increased the national average yield to about 9.5 tha^{-1} [4], which is considered one of the highest averages worldwide.

Rice productivity in Egypt has remarkably increased year after year according to the percentage replacement of rice area with the modern varieties to realize a maximum yield average of 10 tons ha^{-1} in season 2014 against 5.7 tons ha^{-1} for the period 1986–1998. Rice is a semiaquatic plant and very sensitive to water deficit [5–7]. The main constraint of rice cultivation in Egypt is the limited source of irrigation water from Nile River and the shortage of available water, especially in terminal canals in North Delta, whereas rice cultivation is concentrated. In addition, rice consumes large quantities of water during its growing season, which could be directed to reclamation of new lands and planting more crops. Because of adopting of the new short duration and irrigation water stress tolerant rice varieties, about 30% of the irrigation water consumption was saved every year [8].

Rice pests such as weeds, insects, and diseases represent serious problems for sustaining rice yield and quality. The control of such pests increases the production coasts, especially chemical control which has dangerous effects on the environment and human health. Breeding new elite rice varieties with multiple tolerances to such pests is of great importance to save high costs to control it and maintain clean environment.

In this chapter, the history of rice cultivation, varietal improvement, achievements, and challenges of sustaining rice productivity in Egypt will be discussed.

2 Rice Cultivation History in Egypt

2.1 Rice Origin

In the beginning, rice grew wild, but today most countries cultivate varieties belonging to the *Oryza* genus. Twenty-four species of rice belonging to genus *Oryza* were discovered till now. Of them, only two were common and commercially important, the first one is *O. sativa*, the Asian rice species, which is predominantly worldwide and most important, and the second one is *Oryza glaberrima*, the African rice species, which is originated and limited to west and central Africa [9].

Asian rice, *O. sativa*, is one of world's oldest crop species. It is also a very diverse crop, with tens of thousands of varieties known throughout the world. Two major subspecies of rice [10], i.e., *japonica* and *indica* represent most of the world's varieties. Because rice is so diverse, its origins have been the subject of scientific debate. In a study tracing back thousands of years of evolutionary history through large-scale gene re-sequencing concluded that, "domesticated rice may have first appeared as far back as approximately 9,000 years ago in the Yangtze Valley of China" [10].

2.2 Rice Introduction to Middle East and Egypt

The Middle East acquired rice from South Asia probably as early as 1000 B.C. by Persian Empire. The Romans learned about rice during the expedition of Alexander the Great to India [11]. At this time, Egyptians know about rice but they did not cultivate it as a crop. The Arabs brought rice to Egypt when they conquered the country around 640 A.D., perhaps through Spain. Since then, rice has been one of the main crops that plays a key role in the Egyptian economy. The Fayoum region southwest Cairo became the main area for rice cultivation in Egypt at this time. After that, rice cultivation spread to the northern parts of Nile Delta, coastal parts east and west Delta at the six governorates, Kafr Elshiekh, Elgharbia, Elsharqia, Eldakahlia, Elbeheira, and Damietta. More recently, rice was planted at some parts of Port Said, Ismailia, and New Valley governorates.

2.3 Rice Cultivation in Egypt

Rice is cultivated in Egypt at summer season from April till October. Rice cultivation area in Egypt is restricted to the north, east, and west parts of Nile Delta which is because the Ministry of Irrigation guarantees a special irrigation regime. On the other hand, soils of these parts include large areas with various levels of salinity in which rice is grown as a reclamation crop to help leach and lower their salt content. In addition, outside the rice belt, it is also cultivated in a limited area in south delta and middle Egypt at Fayoum governorate (Fig. 1). In average, rice occupies about 22% of the cultivated area in Egypt, about 1.1 million feddans (462,000 ha) during the summer season, thus it consumes about 18% of available water from Nile River [12].

2.4 Egyptian Rice Varieties Before 100 Years

Before one hundred years, rice was grown as a crop for improvement of the soil, so no importance given to improve rice varieties. Rice farmers collected and cultivated non-pure rice cultivars with unknown botanical description. Most of these varieties were grown in a growing period of 180–220 days and were planted as a summer crop; also, there were some cultivars with short duration of 70–95 days which were planted in August as a Nili crop during the River Nile flooding.

The names and brief descriptions of some Egyptian old rice varieties are as follows:

El-Fahl, a variety with long growth, long duration and broad leaves, golden grain with yellow awns, red husk, and slight read grains after milling.

Fig. 1 Rice cultivation area in Egypt

El-Rasheedy, the commercial name of rice varieties that were cultivated and milled at Rosetta governorate.

El-phino, this variety had high drought tolerance, dense roots, tall plant, broad leaves, and long dense panicle with red awns. The milled grains were translucent and had good eating quality.

El-yabani, Yabani Asmar and Yabana Agrah were known with this name. Medium tall and medium short grains with white awns for Yabani Asmar and awn less for Yabana Agrah.

El-Ettihadi, it derived from the name of the company that developed this rice variety. The variety had short growth duration between long dense panicles and medium long grains.

El-Sabeeni, in spite of its low yield and poor quality, El-Sabeeni was grown as a Nili crop in Fayoum governorate because of its very short growth duration 75–95 days. It was tolerant to saline soil.

At this time, the Egyptian farmer called other varieties with many names like El-fayoumi, El-Genwi, El-Seeni, El-Agmi, El-Bokhari, El-Yamani, El-Haddady, El-Hinidi, and El-Manzalawi.

3 Rice Varietal Improvement During the Past 100 Years

Rice varietal improvement efforts started in 1917 after establishment of Plant Breeding Department, Ministry of Agriculture. The Egyptian rice breeding program during the past one hundred years (1917–2017) will be summarized in the following part.

3.1 Period I (1917–1934)

The yield of non-improved varieties at the beginning of this time was very low (<3 tons ha^{-1}). In 1917, the Ministry of Agriculture imported samples of 250 varieties from different countries such as Spain, China, the USA, Japan, India, and Italy. Results of evaluated samples from these collections showed that the *japonica* varieties were more productive than *indicia* varieties [13]. At this period, the Ministry of Agriculture released several new varieties selected from Yabani and Agami strains using individual plant selection. As a result, average yield increased to 3.2 tons ha^{-1} at the end of this period.

3.2 Period II (1935–1954)

During this period (1935–1954), rice yield and production were increased by about 25% which is because of the newly released varieties and application of transplanting method in rice cultivation. Using hybridization as well as pure line selection within the imported Japonica type varieties, some improved varieties were released such as Yabani 15, Yabani Pearl, Yabani Montakhab 5, Yabani Montakhab 7, and Giza 17 which was the first released variety developed thorough hybridization in Egypt [14]. Giza 14 which was derived from cross between Yabani Pearl and Iraki 16 was released in 1953 to Egyptian farmers as a high-yielding variety. Also, some varieties were released at this period with specific traits like Agami M1 (tolerant to salinity), Yabani Momtaz, and Sabeiny Abiad (early maturing for Nili season in Fayoum governorate).

3.3 Period III (1955–1974)

During this period, rice yield in Egypt increased by 40%. High production characterized this phase as a result of two major factors, the doubling of area planted with rice following the completion of Aswan High Dam and the release of high-yielding variety Nahda which derive from a pure line selection in 1955 [15]. Nahda, rice variety was characterized with high yield potential, blast resistance, high milling percentage, less breakage, and good cooking quality. For these reasons, Nahda occupied about 95% of rice cultivation area in 1958 [14]. In addition, three other varieties were bred and released at this period named Arabi, Giza 159, and Giza 170 [16].

3.4 Period IV (1975–1986)

In 1975, Giza 171 and Giza 172 were developed as high blast resistant and equally productive varieties to Nahda, which become susceptible to blast. These two varieties occupied more than 95% of rice area in Egypt by 1980.

Due to the collaboration with International Rice Research Institute (IRRI), which began in the late 1060s, hundreds of new short-stature and high-yielding lines and varieties were introduced to rice research program. The introduced line IR 579-48 was released as Giza 180 because of its yield superiority over Nahad. The Japanese variety Reiho was introduced in 1972 and released in 1983 as a new variety and in 1984 occupied 30% of rice area because of its favorable traits. Put Reiho was severely affected in the same year by new races of blast disease, which prohibited its cultivation ever since.

3.5 Period V (1987–2000)

In 1987, the Rice Research and Training Center (RRTC) (Fig. 2) was established at Sakha, Kafr Elsheikh in cooperation with the United States Agency for International Development (USAID) and IRRI to be interested in rice research, seed production, training, and extension. Since this date, great enhancements in rice production in Egypt were achieved. This has been due to both the increase in yield per unit area as well as increase of total area cultivated with rice.

Progress achieved during this period was mostly brought about by the development and release of promising varieties with high yield potential, earliness, high grain quality, and high blast resistance. The national average yield per unit area recorded 9.3 tons ha^{-1} at the end of this period which represents a 66% increase than that of 5.6 tons ha^{-1} for 1975–1986 period and by 27% of 7.3 tons ha^{-1} for 1987–1997 period.

The total rice production during this period increased from about 2.3 million tons in 1986 to 3.9 million tons, an increase of 1.6 million tons representing 70% increase in total rice production [12]. The outstanding increase in rice production was attributed largely to improved rice productivity per unit area and expanding rice cultivated area. Although the Ministry of Irrigation restricted rice area to be 1 million feddans (0.42 million hectares) annually, it exceeded this limit during this period. The main reason for area increase was preference of farmers to grow rice rather than other summer crops. Farmers considered rice as more profitable because of its high productivity, low cultivation coasts, and reasonable prices.

Fig. 2 Rice Research and Training Center (RRTC) main building, established in 1987 at Sakha, Kafr Elsheikh, Egypt, to be interested in rice research, seed production, training, and extension

During this period, many Egyptian elite rice varieties were developed and released. These varieties were characterized by high productivity, resistant to blast, early maturing, semidwarf, and high grain quality. Some of them were tolerant to abiotic stresses such as salinity and drought. The characteristics of some of these varieties are as follows:

Giza I75, its origin was a breeding line (1394-10-1) selected from the local top cross between IRRI varieties and local variety Giza 14. This variety combined both indica and japonica features, such as short-grain japonica type and short stature (95 cm), short growth duration (135 days), and high blast resistance. Milling outturn is 69%, with high amylose content (28%). Although Giza 175 was acceptable to rice farmers for its high yield potential and other agronomic characteristics, it was less acceptable to Egyptian consumers for its unsatisfactory cooking and eating qualities. Giza 175 had now been replaced by Giza 178.

Giza I76, released in 1991 as japonica type. It was developed from the local cross Calrose 76/Giza 172//GZ 242. It has high yield potential (8–10 tons ha^{-1}), 145-day growth duration, and 100-cm plant height. It has short grains, 70% milling outturn, 19% amylose, and excellent cooking quality. It became susceptible to blast disease after 1993 when its growing area increased.

Giza 177, a popular short-grain, japonica type variety developed from the cross Giza 17l/Yomji No. 1//Pi No. 4 as the breeding line 4120-205. Giza 177 was released in 1995 as the first early maturing variety in Egypt (earlier by about 30–40 days than the old dominant late and tall varieties Giza 171 and Giza 172). Its yield potential is more than 8.3 tons ha^{-1}, about 10% more than Giza 171 and Giza 172. It has high blast resistance, high milling outturn (73%), 18% amylose content, and excellent cooking and eating qualities.

Giza I78, released in 1995 as indica–japonica type developed from the local cross Giza 75/Milyang 49. It is characterized by high yield potential (>12 tons ha^{-1}), 135-day growth duration, 95-cm plant height, with completely erect flag leaves, moderately tolerant to salinity and drought, and lodging resistance. It is resistant to blast disease and is recommended as an early planting variety (first week of May). Giza 178 has short grains with milling outturn about 71% with no white bellies, amylose content is 17%, and it has good cooking and eating quality.

Egyptian Yasmin, released in 1997 as indica type introduced from IRRI as Jasmine 85. Yield potential is about 7.5 tons ha^{-1}, growth duration is 150 days, blast resistant, and plant height is 100 cm with completely erect flag leaves. It has long grains with aromatic scent and amylose content is 19%. Egyptian Yasmin has excellent cooking quality. Although yield of Egyptian Yasmin is lower than that of other commercial varieties, its price is about three times higher.

Sakha 101, released in 1997 as a japonica type derived from hybridization between Giza 176 and Milyang 79. Characteristics include high yield potential (> 12 tons ha^{-1}), 140-day growth duration, 90-cm plant height, and lodging resistance. It was resistant to blast but recently it becomes sensitive. Sakha 101 has short grains, with 72% milling outturn, 19% amylose content, and excellent cooking quality.

Sakha 102, released in 1997 as a japonica type developed from a hybridization between GZ 4098-7-1 (promising line) and Giza 177. It has high yield potential (>10 tons ha^{-1}). Total growth duration is 125 days and plant height is 110 cm. Sakha 102 is blast resistant and it has short grains, 72% milling outturn, l9% amylose content, and excellent cooking quality.

Sakha 103, released in 1999 as a typical japonica plant type, derived from local cross Giza 177/Suweon 349, early maturing (total duration 120 days). It is blast-resistant, with short grains, high milling outturn (73%). amylose content is 18% and has excellent cooking quality.

Sakha 104, released in 1999 as a typical japonica plant type developed from the local cross GZ 4096-8-l/GZ 4100-9-1, and it has high yield potential (>10 tons ha^{-1}) and recommended to grow in normal and saline soils. It has multiple resistances to diseases (blast and brown spots) and insects (stem borers). It has short grains with high milling outturn (73%), translucent milled grains, and excellent cooking and eating qualities.

Giza 182, released in 1999 as indica type developed from the local top cross Giza 181/IR 39422-101-1-3//Giza 181. It has high yielding (>10 tons ha^{-1}), early maturing (125 days), 95 cm plant height, medium long grains, 18% amylose content, and excellent cooking quality.

3.6 Period VI (2001–2017)

This period characterized by static national yield average (around 9.5 tons ha^{-1}, which recorded the world's highest national average yield in 2005) [17]. That could be a result of two reasons: firstly, the yield of developed varieties during this period did not exceed that of the varieties developed during previous period, and secondly, the climate change during this period represented in waves of high temperature during July and August at the same time of rice heading. The high temperature at this time kills the pollen grains and causes failure in pollination and significantly reduces the grain yield. The characteristics of developed varieties during this period are as follows:

Egyptian Hybrid 1, the first hybrid rice variety developed in Egypt, was released in 2005. The hybrid seeds produced from the Cytoplasmic Male Sterile (CSM) line IR65625 A as a female parent and Giza 178R as a restorer parent. It has high-tillering ability and moderate tolerance to salinity and drought. The grain yield is very high (>12 tons ha^{-1}), plant height is 135 cm, growth duration is 135 days, short grains, 70% milling outturn, 19% amylose content, and acceptable cooking quality.

Sakha 105, released in 2010 as a japonica type, developed from cross between the two promising lines GZ 5581-46-3 and GZ 4316-7-1-1. It has high yield potential (10 tons ha^{-1}). Total growth duration is 125 days and plant height is 100 cm. Sakha 105 is blast resistant and it has short grains, 72% milling outturn, 17% amylose content, and excellent cooking quality.

Sakha 106, released in 2013 as a japonica type developed from the cross Giza 177/Hexi 30. It has high yield potential (>10 tons ha^{-1}). Total growth duration is 130 days, moderately tolerant to saline soil and plant height is 110 cm. It is blast resistant and has short grains, 72% milling outturn, 17% amylose content, and excellent cooking quality.

Giza I79, released in 2014 as indica–japonica type developed from the local cross GZ 6296-12-1-2-1-1/GZ 1368-S-5-4. It is characterized by high yield potential (>12 tons ha^{-1}), short growth duration (122 days), 95-cm plant height, moderately tolerant to salinity and drought, and lodging resistance. It is resistant to blast disease. Giza 179 has short grains with milling outturn about 68%, and amylose content is 18%. Although it has high yield and tolerance to abiotic stresses, it is rejected from consumers because of its broken grains during milling.

Sakha 107, released in 2016 as a japonica type drought tolerant variety developed from the cross Giza 177/BL 1. It has high yield potential (10 tons ha^{-1}) under normal conditions and reasonable yield under drought conditions (about 7 tons ha^{-1}). Total growth duration is 125 days and plant height is 110 cm. Sakha 107 is blast resistant and it has short grains, 72% milling outturn, 17% amylose content, and excellent cooking quality.

Super 300, released in 2017 as a japonica type developed by crossing Sakha 101 with introduced variety, to be a restorer for the PTGMS (Photoperiod and Thermosensitive Genetic Male Sterile) lines in Hybrid Rice Breeding program. Plant height is 125 cm and 140 days growth duration. It has high yield potential (>10 tons ha^{-1}), 73% milling outturn, and excellent grain quality.

Some of the modern Egyptian rice varieties are presented in Figs. 3 and 4.

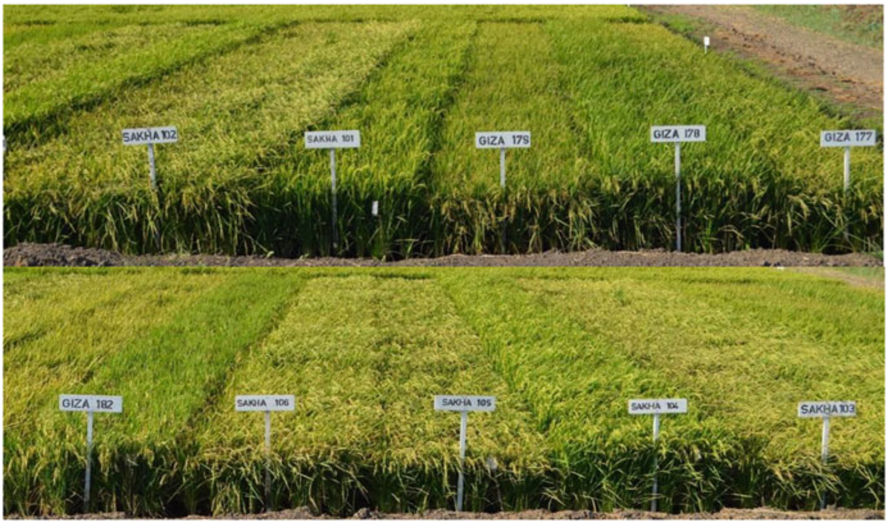

Fig. 3 Some of the modern rice varieties at demonstration field of RRTC

3.7 Current Varietal Improvement Objectives

The main objectives of Egyptian rice breeding program are:

- Collect, evaluate, purify, and maintain all available rice germplasm from different sources to obtain high genetic variability of rice resources to be utilized in different breeding objectives. These rice genetic resources are maintained at Egyptian National Rice Gene Bank which was recently established at RRTC.
- Cooperation with the international institutes working in rice research and plant breeding such as IRRI and AfricaRice Center to exchange and evaluate rice genetic resources and training of young breeders.
- Breed high-yielding varieties of early (125 days) and medium (135–145 days) maturity with high yield potential (>10 tons ha^{-1}) combined with resistance to major biotic stresses such as diseases (blast and brown spots) and insects (stem borers and leaf miners) with short stature (100 cm), and good grain quality.
- Develop high-yielding varieties tolerant to abiotic stress conditions especially salinity, drought, and heat combining early maturity and biotic resistance with good milling quality.
- Develop rice hybrids adapted to Egyptian conditions and consumer preference.
- Develop high-yielding basmati rice varieties for local market and exportation.
- Develop new special rice varieties with specific grain characteristics such as black rice varieties which are rich in minerals, vitamins, and antioxidants.
- Develop high-yielding ideal-type rice varieties (new plant type or super rice).
- Obtain basic information about the inheritance and genetic components of vegetation, yield, and grain quality traits to develop appropriate breeding methodologies.
- Produce breeder, nucleus, and foundation seeds of promising lines and commercial varieties.

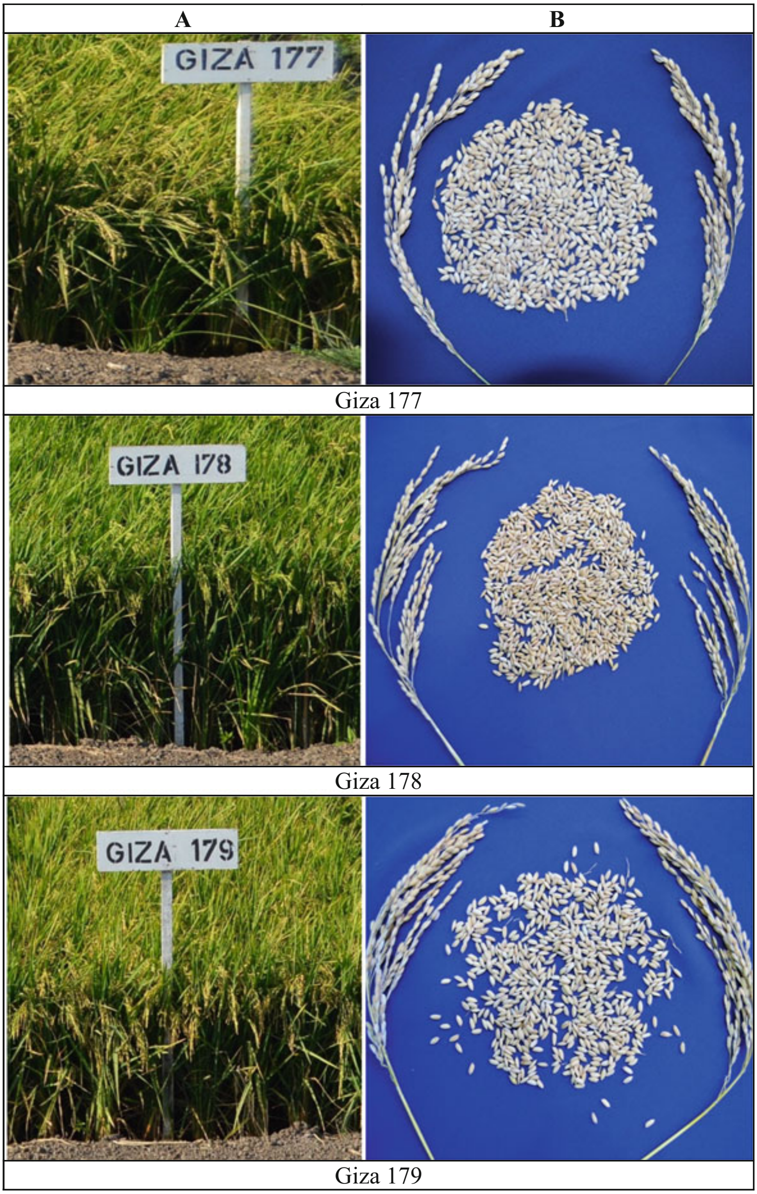

Fig. 4 The plant type (**a**), panicles and grain shape (**b**) of some Egyptian modern commercial rice varieties

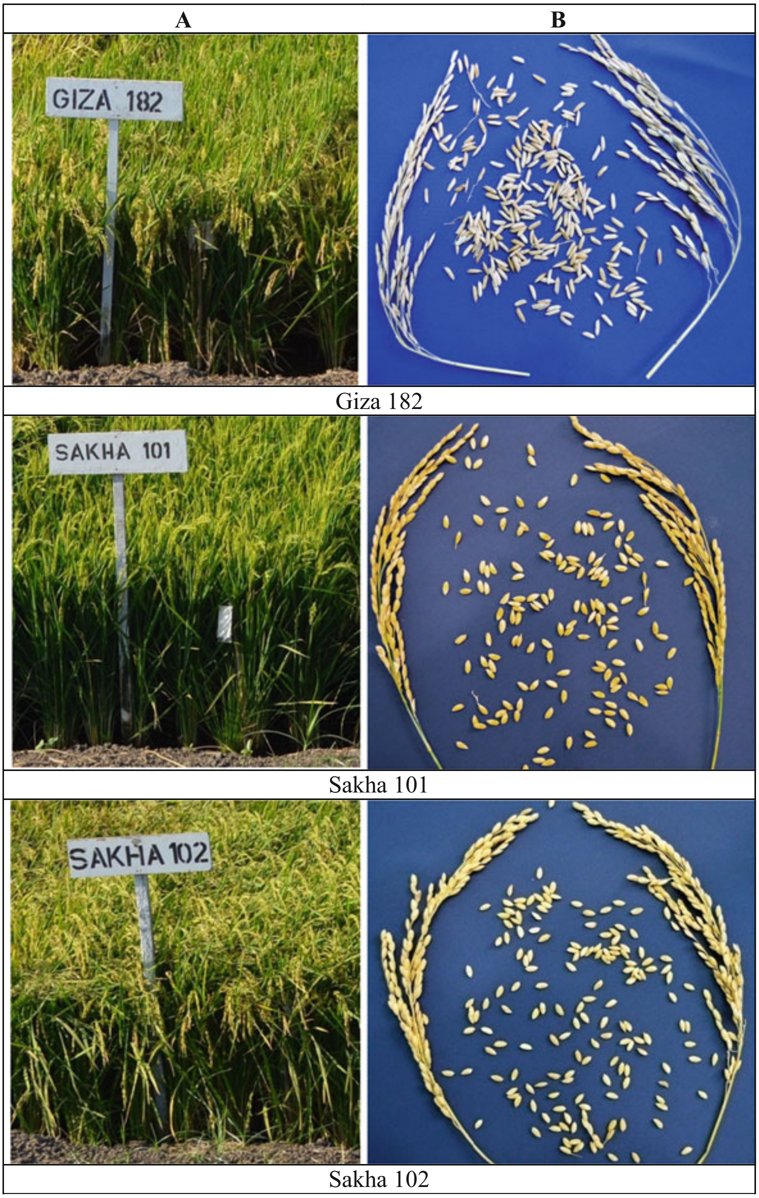

Fig. 4 (continued)

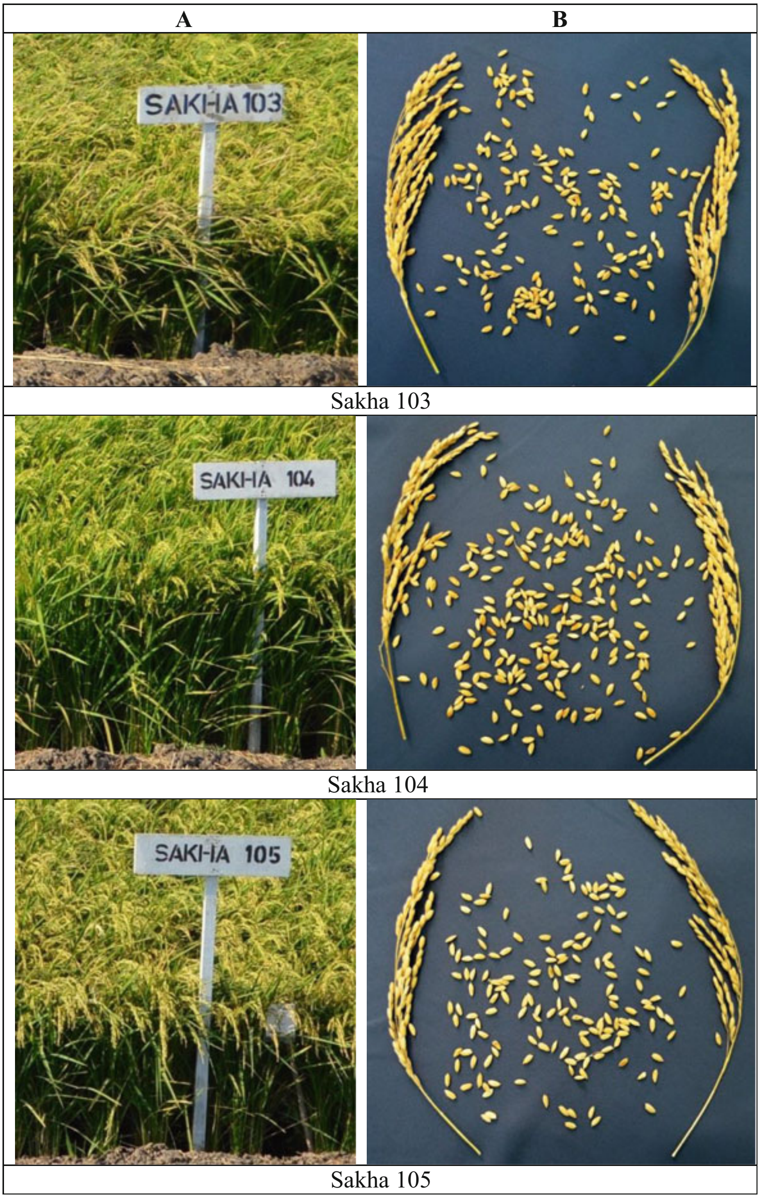

Fig. 4 (continued)

Fig. 4 (continued)

4 Rice Pests in Egypt

Rice cultivations in Egypt are facing many pests such as weeds, insects, and diseases which significantly affect growth, grain yield, and quality, if does not controlled. The average grain yield loss by any of such pests could reach to 30% and could be completely lost as happened in 1984 in Reiho variety cultivations because of blast outbreak. The control of these pests is very expensive and causes high increases in costs of crop production. Meanwhile, the chemical control represents a very dangerous problem on environment, natural enemies, livestock, and human health. So, the development of resistant varieties to such pests is of great importance and had the priority of rice breeders at RRTC.

4.1 Weeds

The weeds grown in rice fields are the main suppressor of rice growth and significantly affecting rice grain yield. Also, the chemical treatments or herbicides for weed control are very dangerous due to the pollution and high production costs. Egyptian rice fields are infected by nineteen major weed species, presented in Table 1 [18, 19].

Among Gramineae species, *Echinochloa crus-galli* L. have become dominant in about 70% of the rice fields, followed by *Echinochloa oryzoides*, *Echinochloa phyllopogon*, and *Echinochloa colona* L. *Cyperus difformis* L. is the most important among Cyperaceae species, which is predominate in about 30% of the rice fields. *Cyperus rotundus* L. is the second most important among sedge weeds. *Scirpus maritimus* L., *Eleocharis geniculata* L., and *Cyperus longus* L. are found in specific areas such as saline areas. Broadleaved weeds found in most rice fields include *Ammannia baccifera* L., *Ammannia auriculata* Wild, *Ammannia multiflora* Roxb. (the most important broadleaved weed) and *Bergia capensis* [20].

Potential yield loss caused by uncontrolled weeds in Egyptian rice fields ranged from 4.42 to 7.60 tons ha^{-1}, with an average yield loss of 6.67 tons ha^{-1} (75%) [18, 19, 21]. Yield loss becomes lowest as 36% in manually transplanted rice compared with 90% losses in direct seeded rice. However, when weeds were controlled at varying degrees, each 100 g m^{-2} dry weight of surviving weeds consisting of grasses (75%), sedges, and broadleaved weeds (25%) reduced grain yield by about 18.5% [21].

Weed management is a combination of several factors, including rice cultivars, planting methods, land preparation, judicious irrigation, time of planting, weed population, allelopathic substance, preventive weed control method, and judicious chemical control methods [22]. Recently, many herbicides were developed which effectively control weeds in rice fields. Allelopathy is the result of biochemical interactions between plants and represents an economic way to control weeds in rice fields. Development of allelopathic rice varieties is very important to naturally

Table 1 Weed species occurring in rice field in Egypt

Weed species	Family
Echinochloa crus-galli (L.) P. Beauv.	Poaceae
Echinochloa oryzoides (Ard.) Fritsch	Poaceae
Echinochloa phyllopogon (Stapf) Koss	Poaceae
Echinochloa colona (L.) Link	Poaceae
Cyperus difformis (L.)	Cyperaceae
Ammannia baccifera (L.)	Lythraceae
Ammannia auriculata Willd	Lythraceae
Ammannia multiflora Roxb.	Lythraceae
Cyperus rotundus (L.)	Cyperaceae
Dinebra retraflexa (Vahl) Panzer	Poaceae
Cyperus longus (L.)	Cyperaceae
Oryza sativa (L.) (red rice)	Poaceae
Paspalum distichum (L.)	Poaceae
Scirpus maritimus (L.)	Cyperaceae
Scirpus juncoides Roxb.	Cyperaceae
Eleocharis geniculata (L.) Roem. and Schult.	Cyperaceae
Eclipta alba (L.)	Asteraceae
Diplachne fusca (L.) P. Beauv. ex Roem. and Schult.	Poaceae
Bergia capensis (L.)	Elatinaceae

control weeds [23]. Figure 5 represents transplanted rice field affected by many types of weeds and chemical treatment of growing weeds.

4.2 Insects

Insect pests are one of the major constraints on rice production. These pests could reduce rice grain yield by about 25%. Insects attack rice plants from the seedling stage to maturity and feed on all parts of the plant (roots, stems, leaves, and grains). Their damage decreases the yield and lowers grain quality [24]. Insects could also attack rice at storage and cause high losses in stored rice. Rice insect management programs had given major emphasis on insecticide use. However, misuse of pesticides is common among rice farmers [25, 26]. Because the use of insecticides is costly, dangerous to workers, can disrupt the agroecosystem, can contaminate unintentionally, and encourages pest insects to develop resistance, there is much interest in developing alternative tactics for integrated insect pest management (IPM) [24].

Rice cultivations in Egypt are liable to attack by several pests (Table 2), but the most important species are the rice stem borer, *Chilo agamemnon* Bles., rice leaf miner, *Hydrellia prosternalis* Deeming, and blood worms, *Chironomus* spp. The control of such insects could be achieved through cultivation of tolerant varieties, cultural practice, and reasonable use of recommended insecticides.

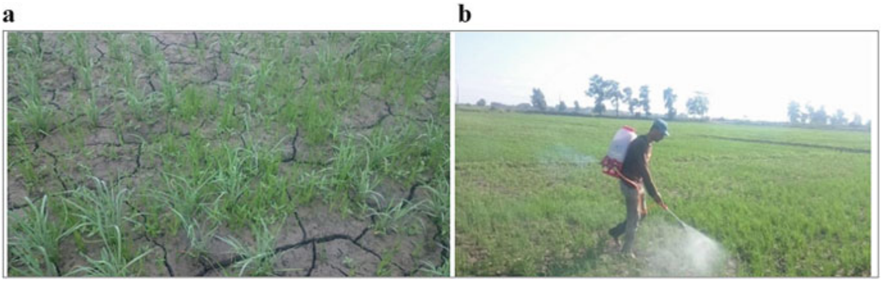

Fig. 5 Transplanted rice field affected by many types of weeds (**a**) and chemical treatment of growing weeds in rice field (**b**)

4.3 Diseases

In general, rice crop is the host of many biotic agents, such as fungi, bacteria, virus, and nematodes. In many tropical countries, complicated situations had resulted from the harmful effects of such biotic agents, thus reducing yields to appreciable levels. In Egypt, the major rice diseases are the fungal diseases: rice blast caused by *Pyricularia oryzae* Cav. (*Magnaporthe grisea*), and brown spot caused by *Helminthosporium oryzae* Breda De Hann. Brown spot disease is common only in poor soils and in cultivations irrigated with drainage water [28, 29].

Other minor diseases isolated and identified are stem rot disease caused by *Sclerotium oryzae* (*Helminthosporium sigmodium*), foot rot caused by *Fusarium moniliforme*, leaf spots caused by *Altemaria* spp., black kernel caused by *Curvularia lunata*, and whit tip disease caused by the nematode *Aphelenchoides besseyi* Christie. False smut that was caused by *Ustilaginoidea virens* was observed for the first time in Egypt in 1997 season on the cv. Giza 171 in Kafr Elsheikh Governorate.

In season 2016, the area of rice crop reached 1,535,000 feddans (644.7 ha) and produced about 6 million tons of paddy rice with an average of 3.9 tons feddan^{-1} (9.3 tons ha^{-1}). Rice diseases, especially rice blast disease, may affect annual rice production by about 5% in normal or mildly infected seasons [28]. In epidemic seasons, yield losses may reach as high as 30–50%. If total annual production is in its highest level (5 million tons), and the price for each tons is about 4,000 Egyptian pounds, the expected yield losses will be about 200 million Egyptian pounds for every 1% reduction in grain yield. This indicates that in normal seasons, expected losses caused by blast infection may reach 1 billion Egyptian pounds per year. Meanwhile, other rice diseases may also lower the production levels, a matter necessitating proper management of such important diseases.

The integrated disease management program which includes resistant varieties, cultural practices, and chemical control was developed at RRTC to minimize the effects of rice blast disease, the most dangerous rice disease in Egypt. As a result of this program, rice cultivations in Egypt was completely clear from blast disease for about 17 years, from 1995 to 2012, until Sakha 101 and Sakha 104 become slightly susceptible. These two varieties are being substituted in the few next years.

Table 2 Common field pests of rice in Egypt [27]

Common name	Scientific name	Family	Order
Rice stem borer	*Chilo agamemnon* Bles.	Pyralidae	Lepidoptera
Rice leaf miner	*Hydrellia prosternalis* Deeming	Ephydridae	Diptera
Bloodworm	*Chironomus* sp.	Chironomidae	Diptera
Mole crickets	*Gryllotalpa gryllotalpa* L.	Gryllotalpidae	Orthoptera
	G. africana Pal de Beauv.	Gryllotalpidae	Orthoptera
Tabanid fly	*Atylotus agrestis* Wied	Tabanidae	Diptera
Stinkbugs	*Nezara viridula* L.	Pentatomidae	Hemiptera
	Nysius ericae (Schill)	Lygaeidae	Hemiptera
Grasshoppers	*Aiolopus strepens* (Latr.)	Acrididae	Orthoptera
	Acrotylus insubricus (Scop.)	Acrididae	Ortheptera
	Euprepocnemis plorans (Charp.)	Acrididae	Orthoptera
	Heteracris littoralis (Ramb.)	Acrididae	Orthoptera
	Anacridium aegyptium L.	Acrididae	Orthoptera
Long-horned grasshopper	*Conocephalus conocephalus* (L.)	Tettigoniidae	Orthoptera
Leafhoppers	*Nephotettix modulatus* Mel.	Cicadellidae	Homoptera
	Balclutha hortensis Lindb.	Cicadellidae	Homoptera
	Empoasca decedens Padi.	Cicadellidae	Homoptera
	Macrosteles ossiumnilssoni L.	Cicadellidae	Homoptera
Planthoppers	*Sogatella capatron* Fen.	Delphacidae	Homoptera
	S. vibix	Delphacidae	Homoptcra
	S. furcifera	Delphacidae	Homoptera
	Oliarus sudanicus Lall.	Delphacidae	Homoplera
Thrips	*Florithrips haegardhi*	Thripidae	Thysanoptera
Field rat	*Arvicanthis niloticus*Dosm.	Muridae	Rodentia
Black rat	*Rattus ruttus rattus* L.	Muridae	Rodenlia
Brown rat	*Rattus norvegicus* Berk.	Muridae	Rodentia
Nile sparrow	*Passer passer domesticus*	Passeridae	Passcrifonnes
Crayfish	*Procambrus clarkii* (Girard)	Cambaridae	Decapoda
	Orconectes virilis (Ha CH)	Cambaridae	Decapoda

5 The Importance of Sustaining Rice Cultivation in Egypt

Rice is one of the major field crops in Egypt. Since it introduced to Egypt at the seventh century, rice cultivation succeeded and grain yield increased year after year. The successful cultivation of rice in Egypt is due to many factors, such as fertile heavy clay soils of north Nile Delta, available irrigation water from Nile River, high solar irradiation during summer season, warm weather, hard workers, the efforts of rice researchers at RRTC to develop high-yielding Egyptian rice varieties and a package of recommendations to maintain maximum grain yield with minimum production costs, and the effective technology transfer and extension program throughout the National Campaign to improve rice yield. As a result of these factors, rice area and productivity increased from 105.9 thousand ha and 3.19 tons ha^{-1} during 1917–1934 period to about 700.0 thousand ha and 9.52 tons ha^{-1} for 2016 season, respectively. The cultivated area during 2016 is much larger than the government's allotment of 452,000 ha. This increased area is attributed to an expected and significant reduction in cottons areas, due to problems associated with the Egyptian cotton industry and the advantages of rice over other summer field crops. Sustaining rice cultivation in Egypt is very important for agriculture, society, and economy.

5.1 Agricultural Importance

Rice crop is cultivated in Egypt at north, east, and west of Nile Delta at around 0.45 million ha (the restricted area of Ministry of Irrigation). About 30% of this area (about 135,000 ha) is salinity affected soils with varied levels. Also, hundreds of thousands of hectares of coastal region are under reclamation. Although rice is not tolerant to high salinity, it is favored in saline soils and, in fact, is preferred over other tolerant crops during the initial stages of reclamation. The maintenance of standing water during the growing season resulted in a significant reduction in the root zone salinity by leaching and dilution of the salts. Leaching is the most effective procedure for removing salts from the root zone of soils. It is most often achieved by pending a good depth of water on the soil surface and allowing it to infiltrate. Leaching is effective when the "salty drainage water is discharged through subsurface drains that carry the leached salts out of the area under reclamation" [30]. Rice is an ideal crop for this purpose. Meanwhile, rice is cultivated at many parts of north coastal areas (about 200,000 ha) which is irrigated with drainage and recycled water, that will be lost in Mediterranean Sea instead.

5.2 Social Importance

Rice is the essential food commodity and carbohydrate source for the large portion of Egyptian population. The total local white rice consumption is estimated to about 4.0 million metric tons during 2015 [31]. The per capita consumption of white rice in Egypt is about 45.0 kg. So, rice is very important food for the Egyptian society. Another socioeconomic importance of rice cultivation is the large number of the labor force working in rice production and processing sector. El-Deeb [32] estimated the labor days needed for cultivating 1 ha with rice in about 124 labor days, which mean about 73 million labor days are required annually during summer season for rice cultivations. Although, the area cultivated with rice is increased, this number is reduced nowadays due to wide utilization of mechanization in rice cultivation. Meanwhile, large number of workers is involved in rice transportation, milling, marketing, and trading activities.

5.3 Economic Importance

Rice cultivated area during 2016 season was estimated at 677,000 ha with productivity of 9.3 tons ha^{-1}, which means production of about 6.3 million tons of paddy rice (4.3 million tons, milled basis) [33]. In 2016/2017, the prices of rough rice fluctuated from 3,800 LE (215 USD) to more than 5,000 LE (283 USD) with average of 4,400 LE (250 USD) for 1 ton. That is, mean rice production in Egypt during this season is equal to 32,560 billion LE (about 2 billion USD).

Egyptian rice export in 2015 is about 400,000 MT [31], with average prices from 650 to 800 USD for 1 MT, so the income from foreign currency is ranged from about 260 to 320 million USD. That is, mean rice production is one of the important sources of hard currency for the Egyptian economy.

6 The Main Challenges of Sustaining Rice Cultivation in Egypt

Rice cultivations in Egypt are facing many challenges, besides the biotic pests mentioned before, there are many other abiotic stresses affecting sustaining rice cultivation and production in Egypt. The main stresses are irrigation water deficit, soil and water salinity, and high temperature during flowering.

6.1 Irrigation Water Stress

Under Egyptian conditions, rice is one of the major water consuming crops, and continuous flooding is the only method used for irrigation. Our share in Nile River water is insufficient for both reclamation and irrigation purposes. Limited water resources and considerable increase in population had forced researchers to find ways to economize the water use without any loss in grain yield.

Research had shown that rice can grow under shallow water far better than under deep submergence. Shallow water increases water temperature during the day and lowers it during the night, thus allowing more tillering and better growth for rice. Most Egyptian rice varieties produce higher grain yields when soil water content is kept near saturation throughout the season to simulate continuous flooding [34]. This indicates that better yield does not necessarily require standing water on the soil surface. Because the water resources in Egypt are limited to 55.5×10^9 m^3 a year, in addition to the tremendous population increase, rice production has to be increased and irrigation water has to be well managed. Finding ways to save irrigation water is of utmost importance.

Cultivation of short duration varieties, such as Giza 177, Giza 178, Giza 179, Sakha 102, and Sakha 107, has been the major approach to reduce water consumption without reduction in yield and area. That could save about 20% of irrigation water without reducing the rice cultivated area. Prolonging irrigation intervals for 6 days at any of the growth stages is another means to save irrigation water under rice conditions. More efforts have to be devoted to educate the rice farmers about the importance of saving irrigation water through improved irrigation methods suitable for newly developed rice varieties. Intensive research to develop more short-duration and irrigation water stress tolerant varieties with high yield potential is also needed.

6.2 Soil and Water Salinity

Soil and water salinity are two of the main constraints of rice cultivation and productivity in Egypt. Rice cultivation belt in Egypt is restricted to the coastal region of Mediterranean Sea northern Nile Delta, and about 30% of this region is saline soil. In general, rice is sensitive to salinity and plant growth and grain yield are affected significantly by both soil and water salinity. Average grain yield of saline soils in Egypt is very lower than that of normal soils, and could be reduced to 50%. Also, this area is irrigated with recycled water with high levels of saline.

6.3 High Temperature During Heading

Climate change during recent years, especially racing temperature, represents a critical problem to rice productivity. The high temperature (more than 40°C) during heading kills the pollen grains resulting in failure in pollination and reduce in grain yield significantly. For the past few years, Egypt faced waves of high temperatures during July and August at the time of rice heading and pollination. These high temperatures affect the fertility of pollen grains and cause high reduction in grain yield per unit area.

The development of multitolerant rice genotypes for such abiotic stresses represents the main objective of rice breeders at RRTC. Many recently released rice varieties were tolerant to abiotic stresses in different levels, such as Giza 178, Giza 179, Egyptian Hybrid 1, and Sakha 107.

7 The Recommendation Package of Rice Cultivation in Egypt

Rice is cultivated in Egypt by many methods such as transplanting, broadcast seeding, and drill-seeded rice. Farmers can obtain the maximum grain yield for each variety with minimum coasts by applying the package of recommendations for each planting method. This package was developed by agronomy component of RRTC as a result of many field experiments designated at many years and regions.

7.1 Transplanting

- The optimum sowing period is from 15 April to 15 May for all rice varieties and any delay beyond this time causes significant yield reduction.
- Optimum seeding rate ranges from 96 to 144 kg ha^{-1}. Seeds should be obtained from a trusty source.
- Seedbed (about one-tenth of the permanent field) has to be close to the water source and to the permanent field at fertile soil.
- Fertilize the seedbed with 36 kg P_2O_5 ha^{-1} before plowing and with 72 kg N ha^{-1} and 48 kg $ZnSO_4$ ha^{-1} after puddling. Soak seeds for 48 h and incubate for 24 h before seeding.
- Apply herbicide Saturn 50% at the rate of 5 l ha^{-1} (after 7–9 days of sewing) to control weeds in the nursery.
- Apply phosphorus fertilizer at the rate of 36 kg ha^{-1} before plowing and then apply 2/3 of nitrogen fertilizer before flooding. About 96 kg N ha^{-1} is recommended for long-stature, low-tillering, and blast-susceptible varieties and 144 kg N ha^{-1} for short-stature, high-tillering, and blast-resistant varieties. Apply the remaining 1/3 of N fertilizer at panicle initiation.
- Optimum age for rice seedlings for most of the Egyptian varieties is 25–30 days.
- Seedlings of high-tillering varieties are transplanted with 3–4 seedlings $hill^{-1}$ at 20×20 cm apart. Seedlings of low-tillering varieties such as Sakha 102 and Giza 177 are transplanted at 15×20 cm spacing.
- Be aware of controlling different pests using recommended pesticides with optimum dosages at right time.

7.2 Broadcast Seeding

- The second half of May is the optimum time for sowing. Optimum seeding rate for most of the Egyptian varieties ranges from 120 to 144 kg ha^{-1}. Soak seeds for 24–48 h then incubate for 24 h to enhance germination.
- Plow the soil twice after applying P fertilizer at the rate of 36 kg ha^{-1}. Apply 1/3 of the N fertilizer before flooding. Apply 24 kg $ZnSO_4$ ha^{-1} after water leveling and then broadcast pre-germinated seeds. Apply another 1/3 of N fertilizer 35 days after sowing. Add the remaining 1/3 of N fertilizer after 65–70 days from sowing (at panicle initiation).
- Apply Saturn 50% at the rate of 5 l ha^{-1} 7–9 days after sowing to control weeds. Many other herbicides were developed recently which could be used.

7.3 Drill-Seeded Rice

- Optimum sowing date is late May. Land has to be well-prepared and well-leveled, and laser leveler is preferred in this case.
- Low-tillering varieties require 144 kg seeds ha^{-1} at 15-cm spacing between rows. High-tillering varieties need 100–120 kg seeds ha^{-1} at 17–20-cm spacing between rows.
- Drill the seeds in the soil about 1-cm deep. Although land has to be irrigated after sowing, excess water needs to be drained after 4–5 h.
- Add 36 kg P_2O_5 ha^{-1} before plowing. Apply 1/2 of N fertilizer 25 days after sowing just before permanent flooding and the second half at panicle initiation. The rate of N fertilizer applied will depend on the variety. Zinc sulfate (at 24 kg ha^{-1}) could also be added before permanent flooding.
- Spray Saturn 50% EC (at the rate of 7 l ha^{-1}) in 100–120 l of water for 2–3 days after the first irrigation.
- Irrigate the fields every 5–6 days.
- Permanent flooding should start 25 days after the first irrigation.
- Do not expose plants to water deficit after the permanent flooding except during application of the second dose of N fertilizer.

8 Conclusions

Rice is very important cereal food crop all over the world as well as in Egypt. Since its introduction to Egypt, rice cultivation and productivity achieved remarkable advances. The national rice research program developed and released many modern Egyptian rice varieties which increased the national average of rice productivity from 5.6 to 9.5 tons ha^{-1} during the last thirty years. Almost all these varieties are resistant to blast disease and many of them are tolerant to different abiotic stresses such as drought, salinity, and high temperature. Cultivation of rice crop in Egypt should be maintained for many social, agricultural, and economic reasons.

9 Recommendations

Finally, it could be recommended that:

- Great attention should be paid to sustain rice cultivations in Egypt.
- Egyptian rice breeders must develop high-yielding biotic and abiotic tolerant rice varieties to cover the local consumption and exportation.
- It is very important to transfer new developed technologies to farmers to achieve maximum grain yield with minimum production coasts.

– Researchers should pay their attention to develop new ways to utilize crop residuals like straw in agricultural and industrial uses to limit its environmental damages.

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Part IV
Biotechnology Application for Agricultural Sustainability

Bioactive Compounds in Soybean Proteins and Its Applications in Food Systems

Mahmoud Sitohy and Ali Osman

Contents

Abstract Soybean has been one of the most important sources of vegetable-sourced proteins. Soybean protein isolate was isolated, characterized, transformed into methylated soybean protein (basic and hydrophilic nature) by esterification with methanol in the presence of hydrochloric acid (50 molar ratio), and tested for their antibacterial activity against pathogenic and spoilage bacteria. Alternatively, glycinin, basic subunit, and β-conglycinin were isolated from soybean protein and tested for their antimicrobial action. Supplementing raw milk with esterified soybean protein (0.5%) reduced the titratable acidity to 0.21, maintaining its pH at 6.4 after 8 days of cold storage compared to 4 days for untreated milk. Similar action was observed when raw milk was stored at room temperature for 10 h. Adding glycinin and the basic subunit to pasteurized milk inoculated with the three bacteria *L. monocytogenes*, *B. subtilis*, and *S. enteritidis* (ca. 5 log CFU/mL) could inhibit their propagation after 16–20 days storage at 4°C by 2.42–2.98, 4.25–4.77, and 2.57–3.01 log and by 3.22–3.78, 5.65–6.27, and 3.35–3.72 log CFU/mL, respectively. The antifungal activities of soy protein fractions glycinin and β-conglycinin against the pathogenic fungus *Penicillium digitatum*, either in vitro or in situ (postharvest orange fruit), were evaluated and compared with the fungicide rhizolax.

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These results suggest that a soy protein fraction containing mainly β-conglycinin can be used as an effective environmentally friendly fungicidal agent against postharvest fungal infections. Native and modified soybean fractions can be used to control the undesirable bacteria and fungus in food improving its safety.

Keywords β-Conglycinin, Antibacterial, Antifungal, Glycinin, Modified protein, Soybean

1 Introduction

Soybean has been one of the most important sources of vegetable-sourced protein. Soybeans are legumes having high protein contents (approximately 40%) as compared to most other legumes [1, 2]. Specific processing has developed different soybean protein products from soybean flour (SF) to isolated soybean protein fractions over the last decades. Soybean protein concentrates (SPC) with over 70% protein and soybean protein isolates (SPIs) with about 85–90% protein are mainly composed of glycinin (11S globulin) and β-conglycinin (7S globulin), which represent 34% and 27% of the whole protein, respectively [3, 4].

The native glycinin is an oligomeric protein having a molecular weight (MW) of approximately 350 kDa and consisting of six subunits (AB). Each subunit is composed of a smaller acidic (MW = 37–42 kDa) (A) and a smaller basic subunit (MW = 17–20 kDa) (B), linked together by disulfide bridges [5]. The β-conglycinin is a kind of trimers composed of three major subunits (α′, α, and β) associated in various combinations by non-covalent interactions [6].

The health benefits of soybean are attributed to the presence of bioactive compounds, in particular proteins isolated and purified from soy bean proteins, e.g., glycinin (11S), basic subunit, and β-conglycinin (7S) have provided antibacterial activity against pathogenic and spoilage bacteria [5, 7–11]. This activity may include impeding spore germination [12] and imparting antioxidants properties [5].

Another approach to obtaining new antibacterial proteins is through the intentionally tailored chemical modifications of native proteins. "Esterification can neutralize the negatively charged carboxyl groups of the aspartyl and glutamyl residues on protein molecules, transforming their net charge into positive. The obtained positively charged proteins were proved antimicrobially active" [13, 14] and inhibited the growth of *L. monocytogenes* and *S. enteritidis* in raw milk [12, 15, 16].

Proteins can be hydrolyzed with acid, alkali, or enzymes to yield peptides or, eventually, amino acids. For example, acid hydrolysis is being used to produce hydrolyzed vegetable proteins, which have meaty flavor profiles. Alkali treatments are used in the production of gelatin. Various enzymatic hydrolytic treatments, however, have become the most important tools for modifying the functionality of dietary proteins [17]. Enzymatically modified proteins have long been available in many conventional foods such as ripened cheese and fermented soya protein products. Moreover, "pure protein hydrolysates have been shown to have valuable dietetic properties and high nutritional value" [18].

2 Bioactive Proteins Derived from Soybean

2.1 *Glycinin (11S Globulin) and β-Conglycinin (7S Globulin)*

2.1.1 Structure and Characterization

Soybean protein is one of the important vegetable protein resources due to its functional properties, high nutritional value, and biological activities. Glycinin (11S) and β-conglycinin (7S), the two major storage protein components in soybean, account for approximately 70% of total storage proteins in soybean seed [19]. Glycinin is a hexameric molecule, and each subunit consists of an acidic (A) and basic (B) polypeptide chain connected by a disulfide linkage. Basically, β-conglycinin is a trimer which consists of α′, α, and β subunits without disulfide linkages [11, 19, 20]; (Fig. 1).

Several methods have been developed for the preparation of 7S and 11S fractions, including ultracentrifugation, fractionation, and reversed-phase high-performance liquid chromatography [21, 22]. "A new method was developed for extraction and isolation of 7S and 11S fractions from soybean seed" [23], based on the methods of Nagano et al. [24] and Thanh and Shibasaki [25].

Optimization of the extraction and isolation of 11S and 7S globulins from soybean seed was investigated under various conditions based on analytical measurements by the Kjeldahl method and SDS-PAGE. The optimal conditions were finally set as follows: 0.03–0.06 M Tris–HCl buffer (pH 8.5) containing 0.01 M sodium bisulfite as the extract solution, where the extraction should be conducted twice at 1:15 ratio (w/v) of flour: Tris–HCl, and 45°C for 1 h. The 11S fraction can be precipitated at pH 6.4, while the supernatant isolated after centrifugation is

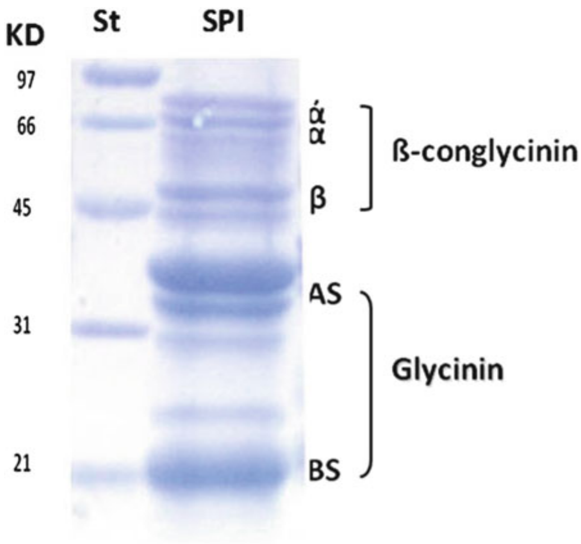

Fig. 1 SDS-PAGE electrophoretic patterns of soybean protein isolate (SPI) [11]

adjusted to pH 5.5 to remove the insoluble intermediate fraction by further centrifugation. The latter obtained supernatant can then be adjusted to pH 4.8 to give off the 7S fraction, which can be isolated by further centrifugation. With the improvements, the protein contents and purities of the isolated 11S and 7S fractions were significantly increased. The contents of all subunits of the isolated 11S and 7S fraction were markedly higher than those by Thanh and Shibasaki's method [25], while the contents of α, β, and B3 were also significantly higher than those by Nagano et al.'s method [24]. Five genetic variants of 11S globulin were identified based on the homology of their subunit sequences, which can be divided into group I ($A_{1a}B_2$, $A_{1b}B_{1b}$, A_2B_{1a}) and group II (A_3B_4, $A_5A_4B_3$) [19]. The sequences of each domain (basic and acidic) in each subunit (G1, G2, G3, G4 and G5) were imported from the Expasy database, https://www.expasy.org/.

2.1.2 Biological Activity

"The health benefits of soybeans are attributed to the presence of bioactive compounds, and in particular proteins" [5]. Glycinin, basic subunit, and β-conglycinin were isolated from soybean protein isolate and tested for their antimicrobial action against pathogenic (*Listeria monocytogenes* and *Salmonella enterica* subsp. *enterica* serovar Enteritidis) and spoilage bacteria (*Bacillus subtilis*) as compared to penicillin. The antimicrobial action of glycinin and its basic subunit against the pathogenic and spoilage bacteria was proved in situ in milk system. This powerful effectiveness was associated with the basicity of the protein fraction, and they can serve as safe antimicrobial agents in preserving food systems. Pasteurized milk can be recontaminated during storage or handling, so adding this small extent of the natural protein may protect milk from contamination and enhance its safety and storage quality. Glycinin and basic subunit may be used to counteract the microbes through inducing an external effect on the microbes if being accessed either in food or in the gastrointestinal tract. These substances can be used alone or as an adjuvant in combination with some antibiotic since they have two different pathways of action [11].

Transmission Electron Microscopy (TEM) images of *L. monocytogenes* and *S. enteritidis* exhibited bigger sizes and separation of cell wall from cell membrane when treated with glycinin or basic subunit. Cells treated with β-conglycinin were the least affected while cells treated with penicillin showed fewer signs of deformations as described in Fig. 2 [11].

The antibacterial characteristics of glycinin basic peptide (GBP) and its effects on the cell membrane of *Escherichia coli* were studied by Li et al. [7]. The activity of glycinin, β-conglycinin and basic subunit in controlling the growth of pathogenic and spoilage bacteria contaminating pasteurized or raw milk was assessed [10, 12, 15].

Glycinin basic subunits (6.25–100 μg/mL) inhibited vigorously VISA P59 as manifested by agar well diffusion assay (Fig. 3). Minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of glycinin basic subunit (GBS) against VISA P59 were 0.8 and 1.6 μg/mL, respectively [8] and controlled the growth of pathogenic bacteria in minced beef meat.

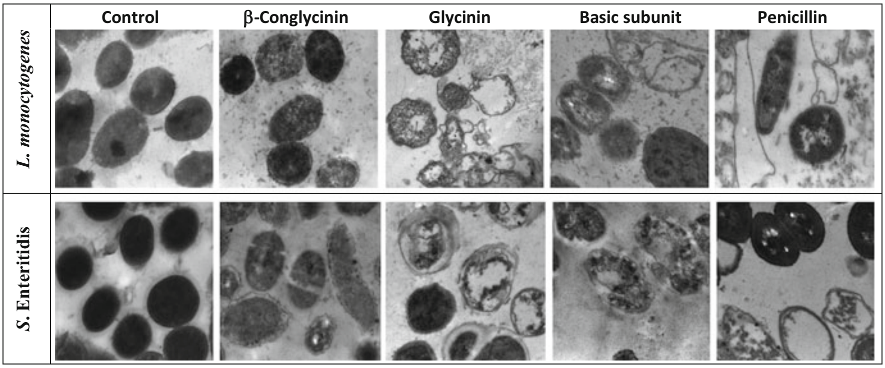

Fig. 2 Transmission electron microscopy (TEM) of *L. monocytogenes* Scott A and *S. enteritidis* PT4 treated with 1 MIC (100 μg/mL) of glycinin, β-conglycinin, basic subunit, and penicillin for 4 h at room temperature [11]

The potential antifungal activities of soy β-conglycinin and glycinin against pathogenic fungus (*Penicillium digitatum*), either in vitro or in situ (postharvest orange fruit), were evaluated and compared to the fungicide rhizolax [9]. The obtained results showed that β-conglycinin could significantly inhibit the in vitro growth of *P. digitatum* at a wide concentration range (50–3,000 mg/L). It could completely inhibit the growth as well as the spore germination of *P. digitatum* at 2,000 mg/L. The MIC and minimum fungicidal concentration (MFC) of β-conglycinin against *P. digitatum* were 50 and 1,900 mg/L, respectively. β-Conglycinin could totally inhibit the green mould in the fruit at a concentration of 250 mg/L during 7 days after infection with the fungus (Fig. 4; [9]).

Impeding *Bacillus* spore germination in vitro and in milk by soy glycinin during long cold storage was studied by Mahgoub et al. [12]. The endospores of *B. licheniformis* were readily recognized under phase-contrast microscopy by their phase bright appearance (Fig. 5, image A1) while the BS-treated spores appeared as dim particles lacking distinct constitution (image A2) probably referring to their adhesion and interactions with BS. The spores of *B. licheniformis* were further examined by a transmission electron microscope (TEM) technique (Fig. 5, images B, C). Visualizing individual spores (image B) showed a normal structure of the control (B1), consisting of three noticeable layers around the core, i.e., cortex, coats, and the surface of the layer. The spore core appeared as a centralized dense structure of approximately 500 nm in diameter surrounded by the cortex without indication of exosporium in accordance with Kim et al. [26]. On the other hand, the individual BS-treated spore (B2) was characterized by the disappearance of some layers, and some microstructures as well as the appearance of torn portions of the outside layer.

B1 and B2 represent the intact control and a BS-treated individual spore (60,000×), respectively. C1 and C2 may be two medium stages of emergent BS-induced vegetative cells breakdown (40,000×) [12].

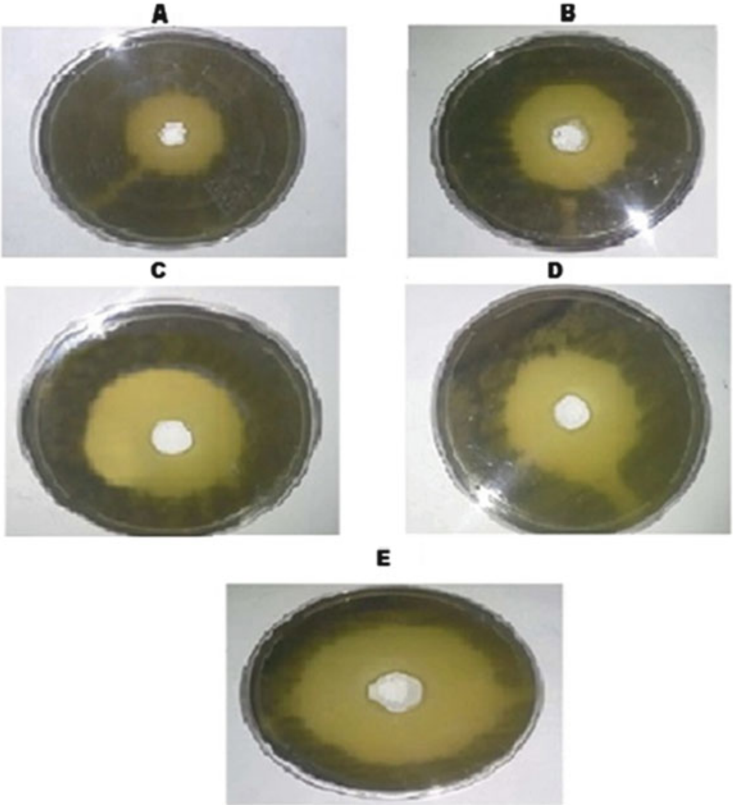

Fig. 3 Inhibition zones on *S. aureus* VISA P59 induced by different concentrations of glycinin basic subunit [8] (**a**) 100 μg/ml; (**b**) 50 μg/ml; (**c**) 25 μg/ml; (**d**) 12.5 μg/ml, and (**e**) 6.25 μg/ml

The size of the treated spore was nearly 1.6 times longer than the untreated spore. Likewise, the size of the core of the treated spore was about 1.5 times greater than the normal. The larger size of the treated spore is probably due to the increased penetration and the entrance of liquid inside the treated spore. Some torn structures can also be visualized (images C1–C2) showing different signs of structural changes or breakdown which may refer to broken emergent BS-affected vegetative cells.

3 Soybean Protein Esters

3.1 Preparation and Characterization

Chemical modification of native proteins was one of the first methods employed to investigate structure–function relationships. Esterification is an important and easy tool for the modification of proteins. Esterification blocks free carboxyl groups thus

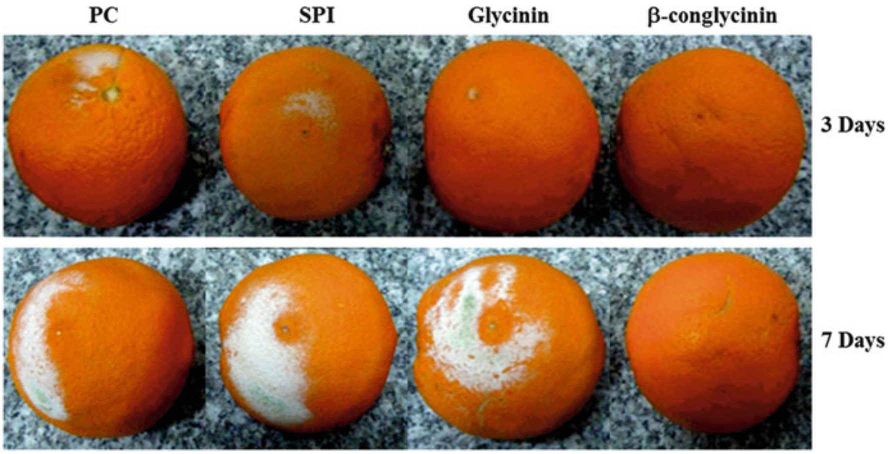

Fig. 4 Orange fruit infected with *Penicillium digitatum* and treated with soy protein isolate (SPI), soy glycinin, and soy β-conglycinin (250 mg/L) after 3 and 7 days of incubation at room temperature [9]

elevating the net positive charge and rendering more basic the modified protein [13, 27, 28] (Fig. 6).

The native PAGE electropherograms of soybean protein before esterification indicate two major bands of around 360 and 200 kDa corresponding to 11S and 7S subunits, respectively, in agreement with Nielsen et al. [30].

The two major fractions of soybean protein (11S and 7S) constitute approximately 80% of the total protein with respective molecular masses of 360 and 150 kDa. The first fraction (11S) is composed of six constituent subunits, each of which consisting of an acidic and a basic polypeptide, linked together by a disulfide bond [30].

The molecular mass of the constituting subunits of 11S and 7S was in the range 20–34 and 50–75 kDa, respectively. The final modified soybean protein prepared by Sitohy et al. [14] is a population of cationic proteins (methylated 11S and methylated 7S) mainly with high and wide molecular mass range (200–360 kDa) but composed of smaller subunits. After esterification, the migration extents of the corresponding bands were slower referring to increased molecular masses as a result of methyl group (Fig. 7; [14]).

The migration in urea-PAGE into cathode direction (Fig. 8; [14]) indicated that esterified soybean protein was much faster than their respective native protein referring to bigger positive charges [14]. Esterification with different alcohols leads to the blocking of free carboxyl groups, thus raising the net positive charge and rendering the modified proteins more basic [27].

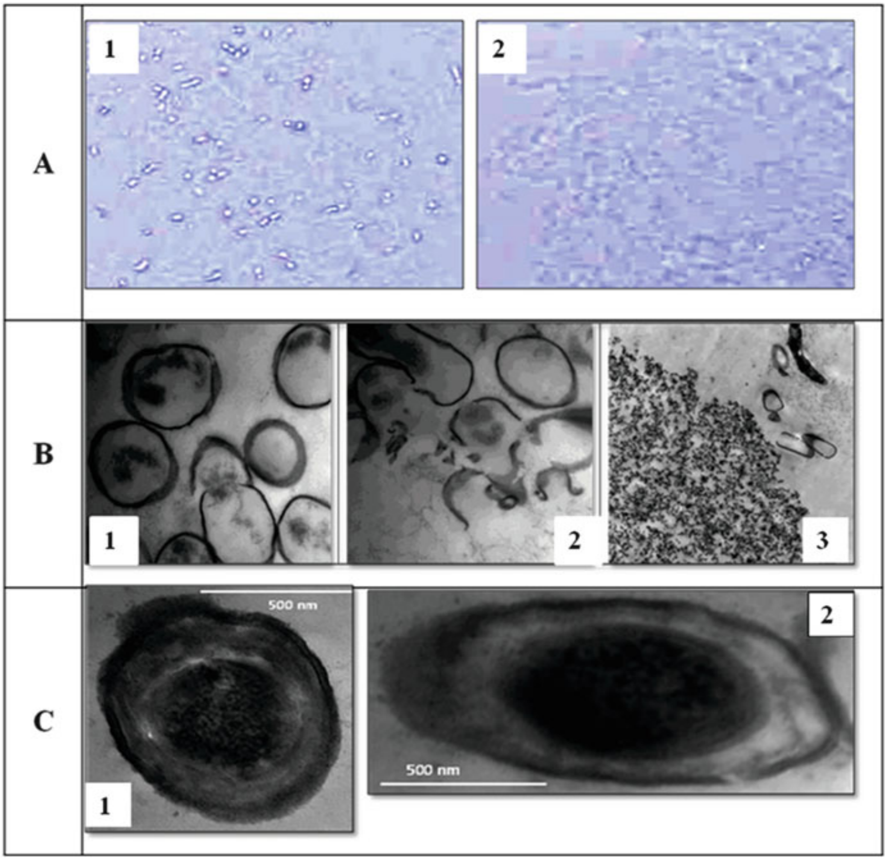

Fig. 5 Phase-contrast light microscopy images (**A**) of the untreated (A1) against BS-treated *B. licheniformis* spores (A2) as well as the transmission electron microscope (TEM) images (**B**, **C**) of the same spores as treated with the BS (100 μg/mL) as compared to control

3.2 Biological Activity

Esterification of soybean proteins turns them positively charged and hence exhibits outstanding antibacterial actions [13, 14]. This action turns the net charge of 7S from negative into positive while it intensifies the positive charge on 11S. This modification eliminates the negative interaction between these two subunits, allowing the whole protein to exert antibacterial action. The current biotechnological technique can provide antimicrobially active cationic proteins. These prepared mixtures of cationic proteins can be invested in the antimicrobial applications without the need to use costly and time-consuming procedures for isolating the active protein component (11S) (http://functionalfoodscenter.net/files/96844636.pdf).

The antimicrobial action of the cationic proteins may be initiated by an electrostatic interaction between their positively charged regions and the negatively

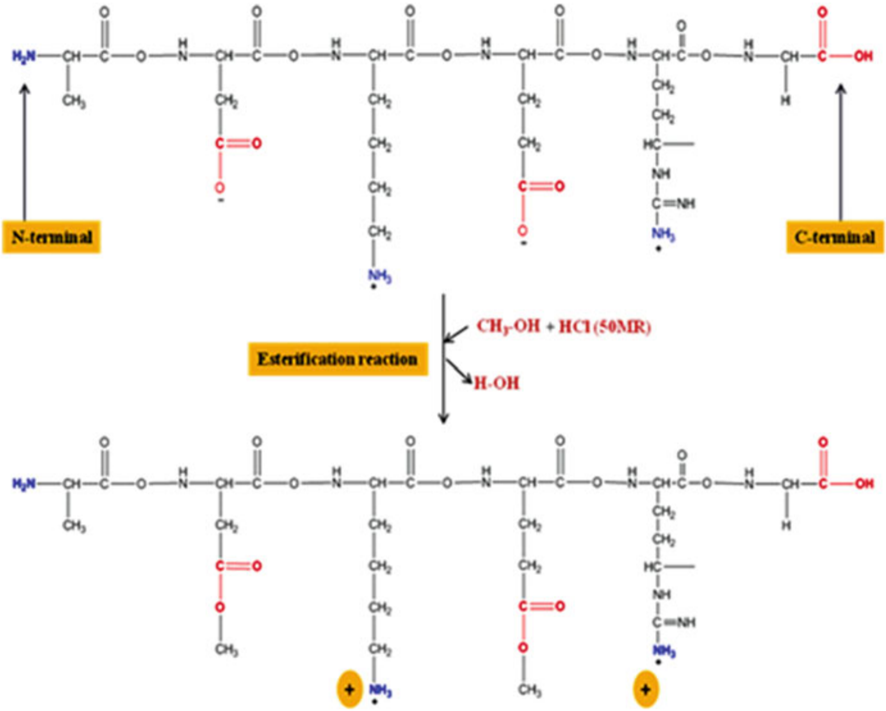

Fig. 6 Protein esterification by methanol [29]

charged regions of the cell wall or cell membrane accompanied by a hydrophobic interaction between alike regions of the two reactants (Fig. 9; [14]).

Sitohy et al. [14] studied the antibacterial action of esterified soybean protein against *Listeria monocytogenes* and *Salmonella enteritidis* and recorded that the minimum inhibitory concentration (MIC) against the two studied bacteria is 100 μg/mL.

The capacity of native and esterified soybean proteins in controlling the growth of pathogenic and spoilage bacteria contaminating raw milk was assessed [12, 15, 16, 31, 32].

4 Conclusions

Soybean protein isolate and its native fractions could be transferred into positively charged proteins by esterification with methanol in the presence of hydrochloric acid (50 molar ratio). The methylated products were proved active against pathogenic and spoilage bacteria. Likewise, glycinin and its basic subunit, the native fractions of soybean protein, were found active against the same bacteria because of their

Fig. 7 Native-PAGE of native (lane 1) and esterified (lane 2) soybean protein [14]

original cationic and hydrophobic nature, while soybean β-conglycinin was found active against fungi due to its glycoprotein nature structure. Supplementation of raw milk with esterified soybean protein (0.5%) proved beneficial since it counteracted the spoilage bacteria maintaining the titratable acidity and pH at normal levels for longer storage period (8 days instead of 4 days of cold storage). Adding glycinin and the basic subunit to pasteurized milk can protect it from the contamination with inoculated bacteria, reducing the bacterial load by about 2.5–3 log after 16–20 days storage at 4°C. A soy protein fraction containing mainly β-conglycinin can be used as an effective environmentally friendly fungicidal agent against postharvest fungal infections with the pathogenic fungus *Penicillium digitatum*, either in vitro or in situ (postharvest orange fruit). These results suggest that native and modified soybean fractions can be used to control the undesirable bacteria and fungus in food improving its safety.

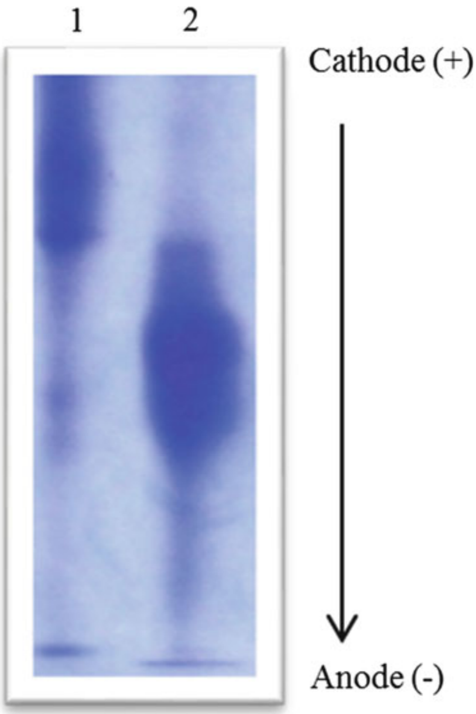

Fig. 8 Urea-PAGE of native (lane 1) and esterified (lane 2) soybean protein [14]

5 Recommendations

More studies are needed to further extract more natural bioactive protein compounds from other legumes and other plants. The specific sequences of certain active protein subunits can also be prepared using genetic engineering tools and cloning strategies. Depending on their sequences other similar products can be prepared and tested for possible activities. Different modifications in the sequences of these bioactive proteins should be also experimented and evaluated using molecular biology tools. The bioactive protein subunits should partially or entirely replace antibiotics and other synthetic antimicrobials in different food and health applications. The maximum antimicrobial actions of these bioactive proteins should be assessed in different food systems to study the possible interactions and effects between them and food components to reach the optimal application conditions. The direct action of such proteins can be directly investigated on animals liable to pathogenic infections as a protecting agent or to infected animals as a remedy.

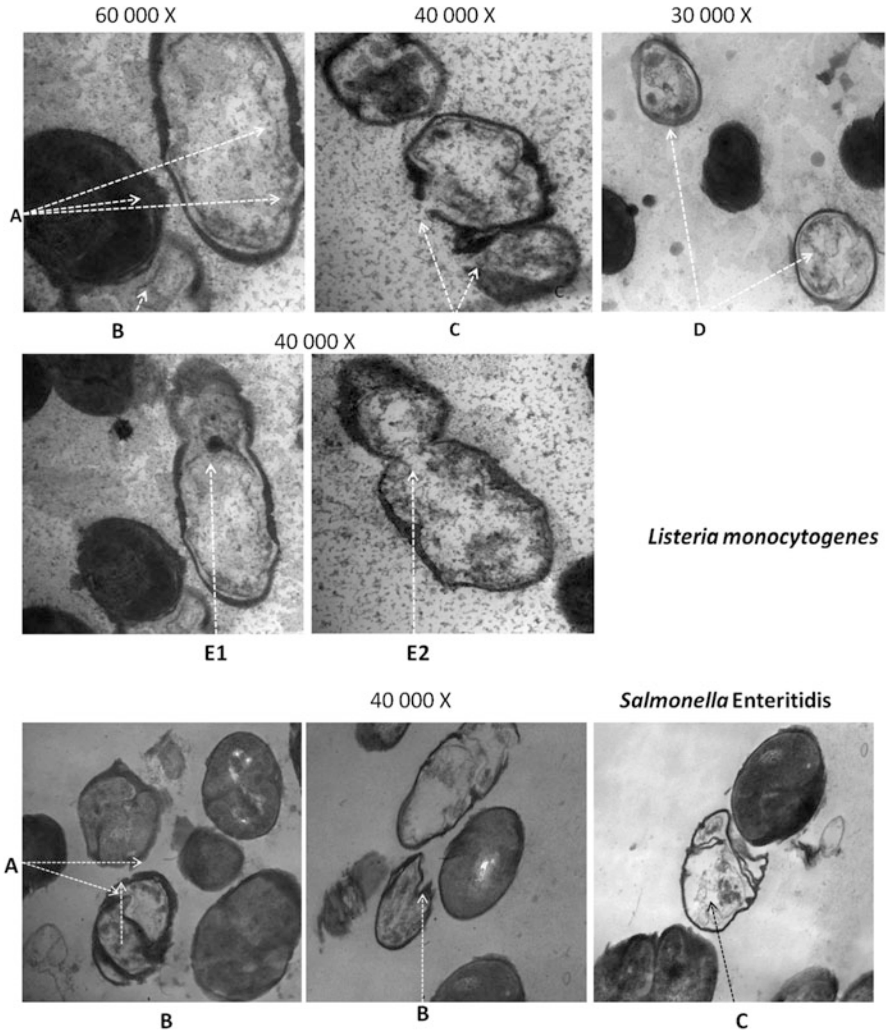

Fig. 9 Possible stages of antimicrobial action of esterified soybean protein on *L. monocytogenes* and *S. enteritidis* PT4 as revealed by TEM. A. Cellular membrane wrinkling, B. Disintegration, C. Poring, D. Cell emptiness leading to ghost cells. E1. Impaired binary division, E2. Failed binary division [14]

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Influence of Natural Plant Extracts in Reducing Soil and Water Contaminants

Abd-Elrahman M. A. Merwad

Contents

Abstract Water is a fundamental and necessary resource for the life of all living things. In recent times, the sources of pure water have become very limited due to various pollution means which arise from the different industrial advancements. Water pollution has significant adverse effects on the environment and humans. *Moringa oleifera* (MO) is a multipurpose tropical tree and is currently cultivated in

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many developing countries, and its seeds contain water-soluble, positively charged proteins that act as an effective coagulant for wastewater treatment. The powdered seed of the MO has coagulating properties that have been used for various aspects of water treatment such as turbidity, alkalinity, total dissolved solids, hardness, and removal of toxic metals. A pot experiment was carried out on lettuce (Lactuca sativa) for the 2016 growing season to study the effect of different water sources, i.e., well water (WW), drain water (DW), sewage water (SW), and groundwater (GW), with or without moringa seed extract (MSE) on reducing water and soils contaminants and its effect on plant growth and heavy metals uptake. Results showed that the lowest values of SSP, SAR, SCAR, RSC, RSBC, PI, PS, KR, and MAR were observed in DW followed by GW, SW, and WW after treated with MSE. The classification of water, i.e., DW, SW, and GW, indicates that all water sources have waters of high salinity-low sodicity before treatment with MSE (C3S1) and moderately low sodicity (C2S1) after treatment with MSE. MSE coagulant has better coagulation capability to reduce water turbidity, NO_3–N, BOD, COD, DO, and heavy metals compared with untreated water. Application of MSE to different water sources increased fresh and dry weight and N, P, and K uptake of lettuce plants compared to the untreated waters. Addition of MSE to different water sources gave a significant decrease in Pb, Cd, Ni, Fe, Cu, Zn, and Mn uptake of lettuce plants compared to untreated water. These decreases represent 33, 34, 6, 11, 24, 12, and 25%, respectively, for WW; 7, 37, 23, 12, 14, 19, and 15, respectively, for DW; 38, 45, 33, 13, 32, 34 and 27, respectively, for SW; and 36, 34, 31, 22, 23, 39, and 23%, respectively, for GW. The soil irrigated with different water sources after treatment with MSE gave a significant decrease in the accumulation of Pb, Cd, Ni, Fe, Cu, Zn, and Mn compared to the soil irrigated with different water sources before treatment with MSE. These decreases represent 33, 57, 25, 18, 14, 29, and 21%, respectively, for WW; 41, 58, 36, 14, 24, 38, and 50, respectively for DW; 44, 67, 32, 27, 26, 49, and 30, respectively, for SW; and 35, 50, 28, 15, 18, 53, and 54%, respectively, for GW. Overall, MSE was enough to improve water quality and remove heavy metals from different water sources, lettuce plants, and soil under study. This preliminary laboratory result confirms the great potential of MSE in wastewater treatment applications.

Keywords Heavy metals, Moringa seed extract, Wastewater, Water quality

1 Introduction

Water is an essential resource for life. Entire living organisms on earth need water for life. However, water can be problematic if it is not available in the right conditions [1]. Humans use water for various purposes. Therefore, the cleanliness of water consumed is vital since water is known to affect health. Today, quality of water becomes a major problem that needs serious attention [2]. Good-quality water has become an expensive item because many water sources have been polluted by waste coming from various human activities. This leads to declining quantity of water sources that could not meet the ever-growing need. In the provision of clean drinking water, besides the quantity and continuity, the quality must meet the applied standards [3]. The ideal water should have some characteristics such as clear, colorless, tasteless, odorless, pathogen-free, harmful chemical-free, and non-corrosive. Water is also expected not to leave sediment in all distribution organs. This standard was set to prevent the occurrence and the spread of waterborne diseases [4–9].

Wastewater may be inherently toxic due to the presence of complex chemical mixtures and thus may mimic diverse modes of action in biological systems. However, instrumental analytical techniques alone may provide little or no information on the potential biological effects of complex environmental mixtures [10, 11].

Over the years, cell-based in vitro bioassays have been extensively employed as a tool to investigate the biological and toxicological effects of individual or admixed chemicals [12, 13]. Wastewater is an alternative source of irrigation water in arid and semi-arid areas because of the severe shortage of pure water [14]. Disposal of wastewater in sandy soils, exceptionally low desert soils in fertility, may be beneficial because of their nutrient content and can improve soil properties. Therefore, the reuse of wastewater has an essential role in agriculture and improving plant growth and yield in these soils [15].

Heavy metals contamination in soil and wastewater-irrigated crops has been reported in some previous studies in Egypt and other developing countries [16, 17]. The concentrations of Fe, Hg, Cd, Pb, Cu, Cr, Zn, Ni, and Mn are present at high levels in the soils irrigated with wastewater compared to those irrigated with different water sources, i.e., fresh water, groundwater, and drain water [18]. Some of these metals can be transferred to the food chain which can affect food quality and cause serious health hazards to human beings and animals [18]. "That may pose potential environmental and health risks in the long term" [19].

To achieve this standard, there is one conventional technique applied in water treatment process, which is coagulation-flocculation. Coagulation is the process of coagulating colloidal particles due to the addition of synthetic materials to neutralize charged particles, thus forming a precipitate due to the force of gravity. Coagulant can be synthetic materials such as ferrous sulfate [$Fe(SO_4)$], aluminum sulfate or alum [$Al_2(SO_4)_3$], and polyaluminum chloride (PAC) [$Al_2(OH)_3Cl_3]_{10}$. The conventional methods of water purification using synthetic materials such as aluminum sulfate (alum) and calcium hypochlorite are not efficient because these materials are imported, thus making the water cost relatively expensive in most economically developed countries and not affordable for the most rural population. Therefore, some people try to get water from dams, mines, small streams, rivers, and lakes. Water from these sources is usually turbid and contaminated with microorganisms that may cause various diseases [20].

Several findings from previous research in [21] demonstrated the use of synthetic materials for water purification could be severely hazardous to health if something goes wrong in their treatment during processing. The report considered the high level of aluminum in the brain is a risk factor causing Alzheimer's disease. Other studies have raised doubt about the feasibility of inserting aluminum into the environment by the use of aluminum sulfate as a coagulant continuously in the water treatment process. However, Davis [22] found no conclusive evidence about the correlation between aluminum and Alzheimer's disease. The treatment processes cover three major operations: coagulation/flocculation, sedimentation, and filtration-disinfection. The natural polyelectrolytes of plant origin have been used for many centuries in developing countries for clarifying turbid water. Even under such conditions, a few plant seeds make effective coagulants for water treatment as compared to those of alum [23]. In laboratory and field studies, MO seed extract has shown promise as a natural flocculant and coagulant that aid in binding the solids in turbid water [24].

Besides synthetic chemicals, there are natural ingredients that can be derived from tropical plants which can be used as coagulants, including moringa seeds (*Moringa oleifera*). The use of natural ingredients from local indigenous plants to clear muddy water is not a new idea [25]. From existing reports, there were allegations that the powder of moringa seeds has antimicrobial properties. Previous research found that moringa is not toxic [26] and recommended for use as a coagulant in developing countries. Various studies have been conducted and showed that moringa seeds are effective as biocoagulant to improve physicochemical properties of contaminated water. MO functions as coagulant through adsorption and neutralization mechanisms. Hassanein et al. [27] reported that moringa defatted seeds powder had conferred protection against cadmium toxicity in wheat. Upon defatted seeds pretreatment, Cd accumulation has diminished three- and twofold in shoots and roots, respectively, and wheat growth and physiological parameters have improved spectacularly. MO has potential as an organic pollutant absorber in simulation solution. MO is reported able to eliminate the turbidity and dissolved organic matters of river water [28]. Damayanti et al. [29] made a membrane consisted of MO and zeolite for palm oil effluent treatment. The present work aims to study the effect of different water sources, i.e., well water (WW), drain water (DW), sewage water (SW), and groundwater (GW), with or without moringa seed extract (MSE) on reducing water and soil contaminants and their effect on plant growth and heavy metals uptake.

2 The Use of *Moringa oleifera* Seed as a Natural Coagulant for Wastewater Treatment and Heavy Metals Removal

Given the widespread environmental pollution which has been expanding in the world, many countries are reviewing their policies regarding handling and management of their resources. The use of synthetic chemical compounds in farming and crop production was expanding at a very rapid pace until the 1960s when pollution started to reach alarming levels. At such time, many developed countries, particularly in Europe and the USA, realized the fearful consequences of environmental pollution. Organic farming was one of the systems which started at such time and was intended to solve the problems. It depends on organo-biological management in crop and animal production with a minimal use of synthetic chemicals (such as fertilizers and pesticides) which are responsible for polluting the environment. Since then, efforts were proceeding to expand using organic materials in raising soil fertility and controlling pests using organic materials. One of such materials is the use plants or their extracts in providing soils and plants with nutrients and controlling plant pests. One of these plants is *Moringa oleifera* plant which is a fast-growing tree (English names: moringa, horseradish, and drumstick tree). It is a native of the Himalayas and is widely cultivated in tropical and subtropical areas, particularly in Asia and Africa, for use as food and feed as well as medicine.

MSE exhibited high efficiency in the reduction and prevention of the bacterial growth in both wastewater and "Sungai baluk" river samples. The turbidity was removed up to 85–94%, and dissolved oxygen (DO) improved from 2.58 to 4.0 mg/L. However, there is no significant difference in pH, EC, and total dissolved solids after treatment. Heavy metals such as iron, copper, and lead were eliminated by 100, 98, and 78%, respectively [30]. Water contamination, surface water polluted by sewage, industrial water discharge and runoff from land clearing and agriculture activities, and groundwater polluted by waste dumping site can be reduced by use of moringa seed powder or extract [31]. Natural resources have been used in water treatment since ancient times but still need to be applied on a large scale. Presently, there is increased interest in the use of plant materials as coagulants and disinfectants in water treatment. A number of plant materials studied are *Moringa oleifera*, *Mangifera indica*, and *Prunus armeniaca* [32]; *Jatropha curcas*, *Hibiscus sabdariffa*, and *Pleurotus tuber-regium* [33, 34]; and *Azardiratica indica*, *Solanum melongena*, *Cynodon dactylon*, *Alternanthera sessilis*, *Anisochilus carnosus*, and *Musa paradisiaca* [35]. Among these plant species, moringa is the most widely cultivated species in terms of its nutritional value and its use as coagulant in water purification [36–39]. The use of moringa seeds for water purification is part of African indigenous knowledge and has been reported to have coagulant property after observing women in Sudan use the seeds to clarify the turbid Nile water [40]. The seeds act as flocculants that attract and aggregate particles held in water suspension, which then precipitate out of the water as flakes, leaving the clearer water. MO seeds also have the potential to remove a wide range of Gram-positive and Gram-negative bacteria, algae, organic pollutants, and pesticides from contaminated water and may produce less sludge than chemical coagulants [28]. However, adequate scientific and technical information are necessary if the full potentials of this renewable biocoagulant are to be fully exploited.

In terms of water treatment applications, MSE in diverse extracted and purified forms have proved to be effective in removing suspended material. MSE generate lower sludge volumes in comparison with aluminum, soften hard water, and act as an efficient adsorbent of cadmium. If a physicochemical treatment applied during the first stage of the wastewater treatment is effective, then the organic load on any subsequent biological treatment phase will be considerably reduced [41]. The major concern in the use of seed extracts for water treatment applications is the residual organic seed material that will be present in the finished water. MSE is organic and biodegradable. If the particulates are removed and the sludge that is generated is proven to be non-hazardous by analysis, then this sludge may be used as a fertilizer and/or soil conditioner after stabilization [41].

At high concentration, metals can exert toxic effects on plants and human health [42–44]. To avoid awful effects on living organisms, heavy metals concentration must not be greater than the maximum allowable concentrations [45]. The threshold concentrations of Cd, Cr, and Pb must be 5×10^{-3}, 50×10^{-3}, and 25×10^{-3} ppm, respectively [45]. These values reflect the potential toxicity of these elements on human health and the environment. According to [46], metals can be classified in the order of decreasing toxicity: Cd > Ni > Pb > Cr. Delmas-Gadras, Fifi, and Defo [46–48] indicated that metals like Cd, Pb, Cr, Cu, Ni, and Zn are most present in urban areas. Equally, Raymond and Okieimen [49] revealed that heavy metals which enter the aquatic environment might be from natural or anthropogenic sources. The powder of MO seed contains some coagulant properties at loading doses of 10 g/L and above that have a similar effect as the conventional coagulum, alum. This lends support to earlier findings of the use of powder processed from MSE as a coagulant in water purification system [50]. The effectiveness of using both natural and synthetic coagulants in turbidity removal was studied. It shows about 70 and 75% removal efficiency for moringa seed and alum, respectively, with respect to its varying parameters [51]. MO seed and *Sclerocarya birrea* nut shells were used to successfully remove selected heavy metals from water samples. The metals were removed from the wastewater efficiently using MSE. At effluent tanks, the percentage trend was Fe > Cu > Pb > Mn > Zn > Cd > Mg [52]. Metals removed from water by using MO seed include arsenic, cadmium, zinc, and nickel. The optimum condition for the removal of arsenic, cadmium, and nickel was 60.2, 85.10, and 90%, respectively [53].

3 Experiment Setup and Design

3.1 *Aim of Study and Design of Experiment*

The experiment was carried out to study the effect of natural plant extract, i.e., moringa seed extract (MSE) in reducing water and soils contaminants and its effect on lettuce plants (*Lactuca sativa*). Four sources of water were collected in October 2016. Well water (WW) sample were taken from Ismailia Canal. Sewage water (SW) samples were taken from Bahr El-Baqar drain, Egypt. Groundwater (GW) samples were taken at a pumping station from Hehia, Sharkia, Egypt. Agricultural drainage water sample was taken from Bilbeis drain, Egypt. The size of the samples was about 200 L of each source. Precaution was taken to avoid sample contamination. Two liters of "samples were filtered immediately and stored in plastic bottles at 4°C until analysis. Samples were analyzed in the laboratory for the major ions chemistry employing standard method" [54]. The criteria for judging the validity of water were soluble sodium percentage (SSP), sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), sodium-to-calcium activity ratio

Table 1 Some physical and chemical properties of the investigated soil

Soil characteristics	Values
Soil particles distribution	
Sand (%)	40.5
Silt (%)	35.2
Clay (%)	24.3
Textural class	Clay loam
Field capacity (FC) (%)	22.9
$CaCO_3$ (g kg^{-1})	15.1
Organic matter (g kg^{-1})	3.6
pH[a]	7.92
EC (dSm^{-1})[b]	1.45
Available N (mg kg^{-1} soil)	62.5
Available P (mg kg^{-1} soil)	12.6
Available K (mg kg^{-1} soil)	194

[a]Soil-water suspension 1:2.5
[b]Soil-water extract 1:5

(SCAR), residual sodium carbonate (RSC), residual sodium bicarbonate (RSBC), permeability index (PI), potential salinity (PS), Kelly ratio (KR), and magnesium adsorption ratio (MAR). Further, the results of the analyses were interpreted using graphical representations like US Salinity Laboratory (USSL) [54].

A pot experiment was carried out on lettuce (Lactuca sativa) for the 2016 growing season under greenhouse conditions to study the effect of moringa seed extract in reducing water and soil contaminants and its effect on plant growth and heavy metal uptake of lettuce. Pots (PVC) were 33 cm in inner diameter and 25 cm deep. Each pot contained 10 kg of air-dried clay loam soil (Table 1); soil properties were analyzed according to [55–57].

3.2 Preparation of Moringa Seed Extract and Treatments of Water Sources

Moringa oleifera seeds used in this study were collected from the farm of the National Research Centre, Egypt. The seeds were de-shelled to remove the kernels. Seed kernels were further dried at ambient temperatures for 5 days (Fig. 2). The chemical composition of MO seed was investigated using [58–60] are represented in Tables 2 and 3. The white kernels were milled into a fine powder using a mill (at 3,000 rpm) and sieved (using 200–250 μm). Twenty grams of the powder was dispersed in 1,000 mL of distilled water. The suspension was stirred for 1 h, settled for 1 h, and filtered of supernatant through a Wattman pleated filter [61]. Five liters of moringa seed extract, previously prepared, was added to 100 L of water from each source and mixed well and left for 24 h (Fig. 1) and then used for irrigation. Two liters of water after adding MLE was stored in plastic bottles at 4°C until analysis

Table 2 The different chemical compounds found in *Moringa oleifera* seed [58]

Chemical	
2,4-Methylene-cholesterol	4-(Alpha-L-rhamnosyloxy)-benzylglucosinolate
Beta-carotene	28-Isoavenasterol
Campestanol	Alpha-tocopherol
Ash 4-(alpha-L-rhamnosyloxy)-	Benzyl isothiocyanate
Brassicasterol	Behenic acid
Carbohydrates	Beta-sitosterol
Fat	Cholesterol
Glucosinolates	Fiber
Palmitic acid	Oleic acid
Stearic acid	Protein
Arachidic acid	

Table 3 Amino acid profile in *Moringa oleifera* seeds (mg/100 g) [59, 60]

Amino acid	Concentration (mg 100 g^{-1})
Lysine[a]	312
Histidine[a]	1,930
Valine[a]	1,080
Leucine[a]	3,830
Isoleucine[a]	4,230
Threonine[a]	3,020
Alanine	5,160
Aspartic acid	1,570
Serine	3,060
Proline	2,180
Glutamic acid	17,870
Glycine	2,370
Arginine[a]	8,280
Cysteine	1,680
Tyrosine	1,970
Methionine[a]	310
Phenylalanine[a]	3,270

[a]Essential amino acids

(Fig. 2). Samples were analyzed in the laboratory for the major ions chemistry employing standard method [54].

3.3 Fertilization and Chemical Analyses of Plant and Soil

The experiment was done in a randomized complete block, in four replicates. The soil watering treatments were applied as percentages of the soil's water holding

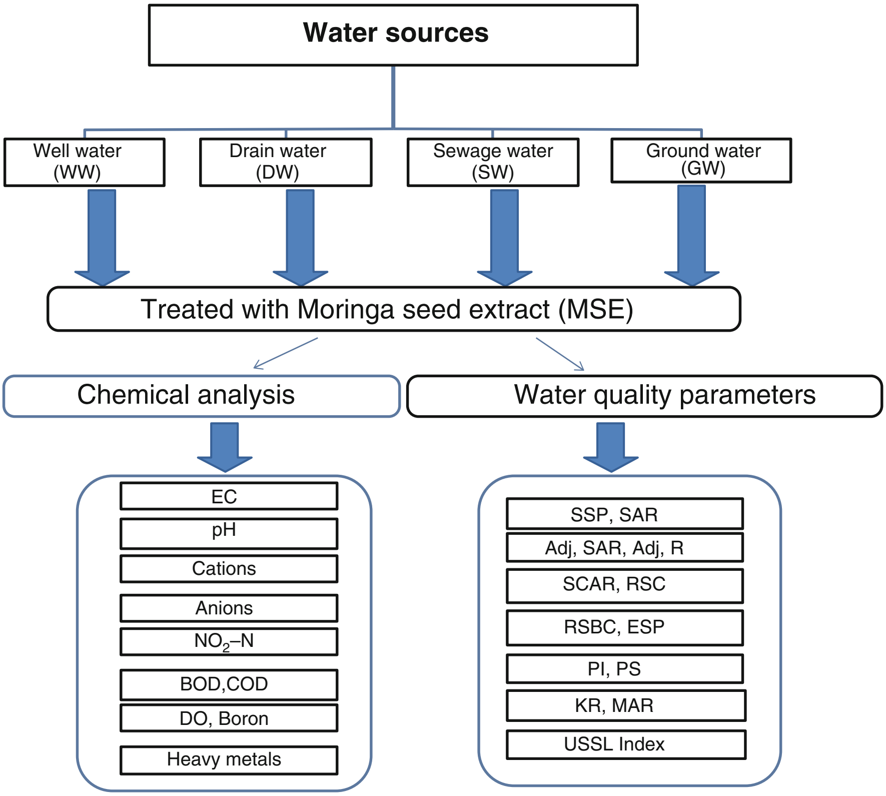

Fig. 1 A flowchart of the methodology

capacity (WHC). Three seedlings pot^{-1} were cultivated, and 2 weeks after sowing, seedlings were thinned to two plants^{-1}. All pots received N, P, and K. Nitrogen was added as ammonium sulfate (205 g N kg^{-1}) at 50 mg N kg^{-1} soil in three equal splits; the first was before the first irrigation, while the second and third splits were 20 and 35 days, respectively, after the first. P was in the form of ordinary super phosphate, 65 g P kg^{-1}, added at 15 mg P kg^{-1} soil, and K was in the form of potassium sulfate, 410 g K kg^{-1}, added at 40 mg K kg^{-1} soil. P and K were added during soil preparation. Pots were weighted daily, and the needed amounts of irrigation water were added for each source.

Samples of plants were taken after 55 days to record plant vegetative characters, fresh and dry weight, and physiological properties. The photosynthetic pigments (chlorophyll a and b and carotenoids) were extracted from the fresh top leaf on main stem samples (three samples, 0.1 g for each) by pure acetone according to Fadeel's method [62].

At harvest, three random plants per pot were taken, with plant height and fresh weight recorded, and dried at 70°C for 72 h. Plant material was ground, and samples were digested and analyzed for N, P, and K [63]. Total phosphorus in the plant was

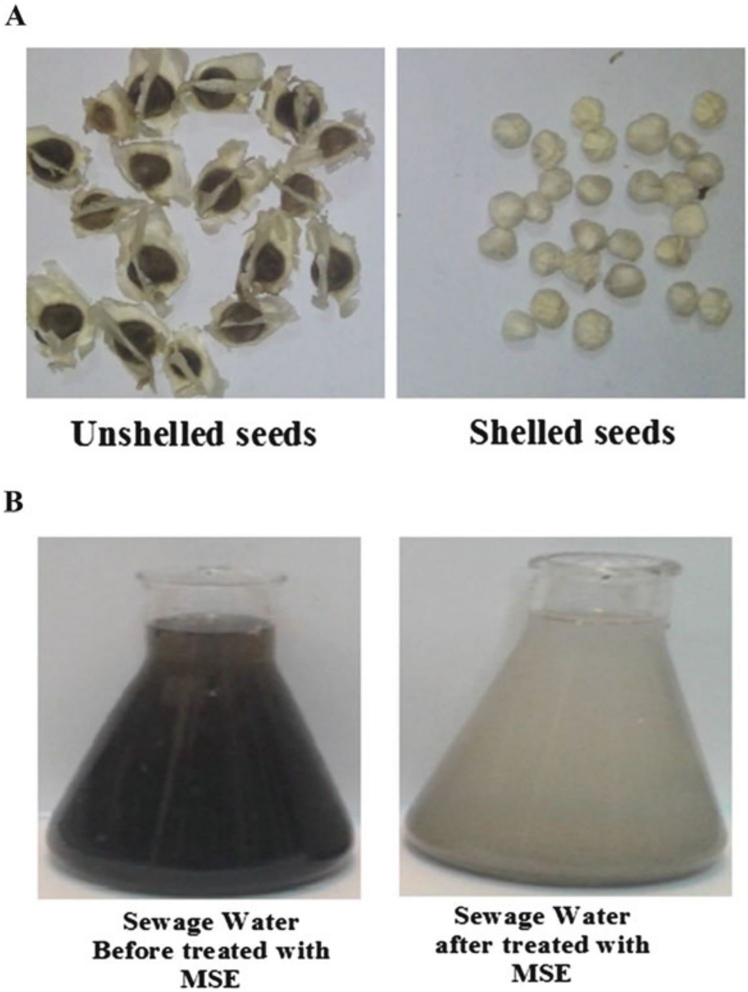

Fig. 2 (**a**) *Moringa oleifera* seeds, (**b**) sewage water with or without moringa seed extract

determined colorimetrically using ascorbic acid method [64]. Concentrations of some heavy metals were determined using atomic absorption spectrophotometry according to [65]. Soil samples were taken after harvesting, and heavy metals were determined using atomic absorption spectrophotometry according to [65].

3.4 Statistical Analyses

Data of the current study were subjected to an analysis of variance for a split block design, after testing for the homogeneity of error variances. Statistically significant differences between means were compared at $P \leq 0.05$ using Duncan's multiple range test. The statistical analysis was carried out using COSTAT computer software (CoHort Software version 6.303, Berkeley, CA, USA).

4 Water Analysis Results

4.1 Effect of Moringa Seed Extract on the Chemical Composition of Water Sources

Table 4 shows EC, pH, and the ionic composition of water sources, i.e., well water, drain water, sewage water, and groundwater, before and after treatment with MSE. The EC and pH ranged from 0.50 to 1.68 mS/cm and 7.50 to 7.76, respectively, from water sources. The highest EC and pH were obtained with drain water before treatment with MSE, while the lowest EC and pH were obtained with well water after treatment with MSE [59, 66–68].

According to [69], salinity classes range from low to very high. Water in drain water, sewage water, and groundwater before treatment with MSE is of high salinity (C3), which should be used on soils with unrestricted drainage, and if used in soil with restricted drainage, special management for salinity control should be done, and salt-tolerant plants should be used. Water in drain water, sewage water, and groundwater after treated with MSE is of moderate salinity (C2), which should can be used for can be used for all but extremely salt-sensitive crops when grown on soils of high to medium permeability. With soils of low permeability. Some leaching and times growing moderate salt tolerant crops are necessary. Relative abundance of cations in water of WW, DW, SW, and GW was $Ca^{+2} > Mg^{+2} > Na^{+} > K^{+}$, respectively. Regarding anions abundance in water of WW, DW, SW, and GW was $Cl^{-} > HCO_3^{-} > SO_4^{-2} > CO_3^{-}$, respectively.

Data recorded in Table 4 showed that pH of water sources was not significantly changed after treatment with MSE. "The main use of pH in a water analysis is for detecting abnormal waters. The normal pH range for irrigation water is from 6.5 to 8.5" [70]. An abnormal value is a warning that the water needs further evaluation. Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion [19]. This result agreed with the findings of [50, 68, 71].

4.2 Effect of Moringa Seed Extract on Water Quality Parameters

Table 5 shows soluble sodium percentage (SSP), sodium adsorption ratio (SAR), sodium-to-calcium activity ratio (SCAR), residual sodium carbonate (RSC), residual sodium bicarbonate (RSBC), permeability index (PI), potential salinity (PS), Kelly

Table 4 Effect of moringa seed extract on chemical composition of water sources

Factor of study		EC	pH	Cations (mmolc l^{-1})				Anions (mmolc l^{-1})			
				Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}
Effect of water source (a)											
WW		0.41d	7.51d	2.62d	0.79d	0.30d	0.36	0.00	0.86d	2.88c	0.32d
DW		1.43a	7.73a	4.06c	3.78a	4.06a	0.67	0.00	4.73a	5.25b	2.59a
SW		1.22b	7.64b	4.49a	3.15b	3.50b	1.01	0.00	3.66b	6.43a	2.07c
GW		1.14c	7.62c	4.48b	2.29c	3.35c	1.24	0.00	3.71c	5.26b	2.39b
Effect of MSE (b)											
Without		1.44a	7.64a	3.96b	3.28b	5.13a	1.11a	0.00	4.18b	5.99b	3.31a
With		1.32b	7.60b	7.7a	3.43a	0.95b	1.05b	0.00	4.59a	7.83a	0.74b
*Effect of interaction (a * b)*											
WW	Without	0.50f	7.52	3.23e	0.97f	0.37e	0.44e	0.00	1.06f	3.55f	0.39e
	With	0.31g	7.50	2.00f	0.60g	0.23f	0.27f	0.0	0.66g	2.20g	0.24g
DW	Without	2.00a	7.76	4.13d	4.17b	7.49a	0.74c	0.00	6.70a	5.27c	4.57a
	With	0.86d	7.71	3.99	3.38c	0.63d	0.60d	0.00	2.76e	5.22c	0.61d
SW	Without	1.68b	7.66	4.12d	4.82a	6.47b	1.39b	0.00	4.36c	8.62a	3.82c
	With	0.75e	7.62	4.86a	1.48e	0.53	0.63	0.00	2.96d	4.23d	0.32e
GW	Without	1.56c	7.65	4.36c	3.17d	6.20c	1.87a	0.0	4.6b	6.52b	4.47b
	With	0.71e	7.60	4.60b	1.40e	0.50d	0.60d	0.00	2.80d	4.00e	0.30ef

WW well water, *DW* drain water, *SW* sewage water, *GW* groundwater, *MSE* moringa seed extract

Mean values in the same column for each trait followed by the same lowercase letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$

Table 5 Effect of moringa seed extract on water quality parameters

Factor of study		SSP	SAR	Adj. SAR	Adj. R Na	ESP	RSC	RSBC	SCAR	PI	PS	KR	MAR	USSL index
Effect of water source (a)														
WW		7.41d	0.23d	0.32c	0.19s	−0.33d	−2.54a	−1.76d	0.19d	30.57d	3.51d	0.08d	23.09d	C2S1
DW		25.95a	2.01a	4.30a	2.49a	1.73a	−3.11c	0.49a	2.01a	45.59b	6.54s	0.50a	48.29a	C3S1
SW		22.79c	1.68c	3.60b	1.99c	1.23bc	−3.98d	−0.63b	1.72b	44.13c	5.41c	0.41c	38.60b	C3S1
GW		23.37b	1.75b	3.69b	2.08b	1.33b	−3.06b	−0.78c	1.60c	47.07a	6.46b	0.45b	32.72c	C3S1
Effect of MSE (b)														
Without		32.96a	2.57a	5.45a	3.06a	2.84a	−3.06a	0.23a	2.53a	52.66a	6.61a	0.65a	42.45a	C3S1
With		6.80b	0.26b	0.51b	0.31b	−0.86b	−3.28b	−1.57b	0.22b	31.02b	4.35b	0.07b	28.90b	C3S1
*Effect of interaction (a * b)*														
WW	Without	7.42d	0.26e	0.41f	0.23f	0.23g	−3.14d	−2.17g	0.21f	30.63f	3.70f	0.09d	23.10e	C2S1
	With	7.39de	0.20	0.23g	0.15g	−0.89d	−1.94b	−1.34e	0.16g	30.50f	3.32g	0.07e	23.08e	C2S1
DW	Without	46.2a	3.76a	8.05a	4.70a	4.35a	−1.60a	2.20a	3.76a	63.80a	7.55b	0.93a	50.70b	C3S1
	With	5.7f	0.26e	0.55e	0.27e	−0.89d	−4.61g	−1.23d	0.25d	27.37g	5.53d	0.07e	45.87c	C2S1
SW	Without	38.5c	3.06c	6.56c	3.47c	3.29b	−4.58g	0.65b	3.19b	55.5b	6.42c	0.75c	53.9a	C3S1
	With	7.07de	0.30d	0.64d	0.50d	−0.83ef	−3.38f	−1.9f	0.24de	32.76d	4.39de	0.07e	23.30e	C2S1
GW	Without	39.7b	3.20b	6.77b	3.82b	3.49c	−2.92c	0.25c	2.97c	60.7c	8.76a	0.82b	42.1d	C3S1
	With	7.04e	0.29de	0.61de	0.33e	−0.84e	−3.2de	−1.8f	0.23de	33.44e	4.15e	0.08e	23.33e	C2S1

WW well water, *DW* drain water, *SW* sewage water, *GW* groundwater, *MSE* moringa seed extract, *SSP* soluble sodium percentage, *SAR* sodium adsorption ratio, *SCAR* sodium-to-calcium activity ratio, *RSC* residual sodium carbonate, *RSBC* residual sodium bicarbonate, *PI* permeability index, *PS* potential salinity, *KR* Kelly ratio, *MAR* magnesium adsorption ratio

Mean values in the same column for each trait followed by the same lowercase letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$

ratio (KR), and magnesium adsorption ratio (MAR) in water sources as affected by MSE. The lowest values of SSP, SAR, SCAR, RSC, RSBC, PI, PS, KR, and MAR were observed in DW followed by GW, SW, and WW after treatment with MSE. The classification of water, i.e., DW, SW, and GW, indicates that all water sources have waters of high salinity-low sodicity before treatment with MSE (C3S1) and moderately low sodicity (C2S1) after treatment with MSE according to [69] classification. According to [69], waters from different sources could be used safely for irrigation purposes since RSC values are less than 1.25.

According to the classification of [72], waters from different sources are considered non-alkaline water and could be used on almost all soils for all crops for indefinitely long periods without any problem. Different water sources are of good quality for irrigation purposes since PI values are lower than 75. The PI ranges from 30.5 to 60.7%, which comes under class I of Doneen's chart. The PS values of the drainage water samples in the study area were 3.3, 5.5, 4.3, and 4.1 mmolc/l for WW, DW, SW, and GW, respectively. After treatment with MSE. Therefore, the tested water falls under recommended permissible. According to the classification of KI, waters in different sources have KI of <1.0; therefore, they could be used for irrigation. MAR values were 23.0, 45.8, 23.3, and 23.3 for WW, DW, SW, and GW, respectively, after treatment with MSE. Therefore, the water is suitable for use in irrigation since the values are <50 in waters of the three drains. This result agreed with the findings of [59, 66, 67].

4.3 *Effect of Moringa Seed Extract on Turbidity, NO_3–N, BOD, COD, DO, and Removal of Heavy Metals*

Table 6 shows turbidity, NO_3–N, BOD, COD, DO, and the concentrations of B, Fe, Zn, Cu, Mn, Pb, Ni, and Cd in water sources as affected by MSE. MSE coagulant has better coagulation capability to reduce water turbidity compared with untreated water that was able to reduce turbidity by 74.6, 74.8, 80.1, and 68.2% in WW, DW, SW, and GW, respectively. Turbidity in the water is caused by suspended solids, both organic and inorganic substances. Inorganic substances include crack of rock, sand, mud, and dissolved metals. Organic matter originating from domestic and industrial waste could serve as a good environment for bacteria to grow. Besides microorganisms, algae and plankton can also cause cloudiness in the water [70].

From the data presented in Table 6, results showed that the application of MSE gave lower values of NO_3–N, B, and metals, i.e., Fe, Zn, Cu, Mn, Pb, Ni, and Cd, in WW, DW, SW, and GW than those untreated waters. These decreases represent 48, 25, 25, 5.8, 3.2, 29, 6.8, 16, 17, 0, 0, and 0% for WW, respectively; 77, 56, 18, 31, 17,50,19, 17, 36, 43, 41, and 46% for DW, respectively; 87, 63, 17, 7, 88,

Table 6 Effect of moringa seed extract on turbidity, NO3–N, BOD, COD, DO, and removal of heavy metals

Factor of study		Turbidity (NTU)	mg L^{-1}											
			BOD	COD	DO	NO_3–N	B	Fe	Zn	Cu	Mn	Pb	Ni	Cd
Effect of water source (a)														
WW		12.85d	22.9d	115d	7.15c	5.05d	0.61d	17.15d	1.55d	1.1d	11.25d	0.0d	0.0d	0.0d
DW		90.75b	55.45b	273c	11.7b	30.95a	2.83b	55.6b	1.99b	2.09ab	15.45b	2.51b	2.06b	1.165a
SW		182a	135a	307a	13.95a	17.85c	13.70a	62.15a	2.11a	2.28a	19.7a	5.6a	3.07a	1.56b
GW		21.15c	21.85c	249b	11.0b	24.25b	1.08c	47.9c	1.845c	1.35c	14.1c	2.28c	1.13c	0.83c
Effect of MSE (b)														
Without		125a	96.7a	326a	12.1a	25.17a	7.38a	59.95a	2.0a	1.86a	18.25a	3.45a	2.13a	1.17a
With		28.15b	21.2b	146b	9.8b	13.87b	1.73b	31.45b	1.75b	1.55b	12b	1.74b	1.01b	0.60b
*Effect of Interaction (a * b)*														
WW	Without	20.5f	30.2c	132f	8.2f	5.2f	0.62f	20.1g	1.61ef	1.20ef	12.3ef	0.00f	0.0f	0.00f
	With	5.2h	15.6g	98.7g	6.1g	4.9fg	0.60f	14.2h	1.50f	1.0f	10.2g	0.00f	0.0f	0.00f
DW	Without	145b	90.3b	380b	12.9b	36.6a	3.1a	73.9b	2.20b	2.30b	18.9b	3.2bc	2.6b	1.51b
	With	36.5d	20.6e	166d	10.5e	25.3de	2.56c	37.3e	1.78e	1.89d	12.0e	1.82d	1.52d	0.82d
SW	Without	305a	241a	450a	15.3a	32.4b	2.46cd	85.3a	2.30a	2.56a	25.3a	7.6a	4.5a	2.2a
	With	60.7c	30.2c	165d	12.6c	30.3c	2.81b	39.0d	1.92c	2.01c	14.1d	3.6b	1.65c	0.92
GW	Without	32.1e	25.3d	342c	12.0cd	26.5d	1.2d	60.5c	1.89cd	1.40e	16.5c	3.0c	1.42de	1.0c
	With	10.2g	18.4f	157e	10.0e	22.0e	0.97e	35.3f	1.80de	1.30e	11.7f	1.56e	0.85e	0.66e

WW well water, *DW* drain water, *SW* sewage water, *GW* groundwater, *MSE* moringa seed extract, *BDO* biological oxygen demand, *COD* chemical oxygen demand, *DO* dissolved oxygen

Mean values in the same column for each trait followed by the same lowercase letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$

54, 16, 21, 44, 53, 63, and 58%, respectively, for SW; and 27, 54, 46, 17, 19, 42, 4.8, 7.1, 29, 48, 40, and 34%, respectively, for GW. Thus, these findings agreed with what was deduced by Subramanium et al. [73]. High levels of heavy metals are typically associated with severe health effects [74, 75]. MO seed cake acts as a natural adsorbent to remove the heavy metals from water samples. MSE reduced 98.6% turbidity of wastewater, 10.8% of its conductivity, and 11.7% of its BOD and removed its metal contents (Cd, Cr, Mn). When applied to groundwater, MSE removed the turbidity of groundwater as much as 97.5%, while it reduced the conductivity and BOD of groundwater to 53.4% and 18%, respectively [66, 67].

In this study, the increasing MSE concentration showed high efficiency in the removal of the heavy metals from the "Sungai baluk" river samples. Subramanium et al. [73] reported that MO seed cake has been able to remove copper (Cu) up to 90%. The concentration of Cu after the treatment was in the range of the standard drinking water. Apparently, more than 90% of Cd was removed. The result was similar to what was found by Meneghel et al. [74]. However, Vikashni et al. [75] confirmed that only 60% of Cd could be removed by using MSE. The level of Fe was entirely removed by MSE. This result totally agreed with what was concluded by Sajidu et al. [76]. Regarding Pb level, although MSE showed some reduction of Pb in the treated water, the result was not good enough to meet the drinking water standards [70]. Pb has been reduced up to 0.537 mg/L; however, this value was considered higher than the acceptable concentration of Pb which should be less than 0.05 mg/L. The percentage of the removed Pb in our study was 70%, whereas it had been 89 and 80%, respectively, in the studies carried out by Subramanium et al. and Sajidu et al. [73, 76].

This study proved that the coagulant might reduce the level of heavy metals in the sewage water. This could be due to the addition of a coagulant that will form flocs and pull those metals into the flocs. Chemical sewage water treatment is usually performed to remove particles that are not easily precipitated (colloidal), including heavy metals. With the addition of a coagulant, removal of such materials, in principle, takes place through changes in the properties of these materials, which can be precipitated from not easily deposited (coagulation-flocculation), either with or without oxidation-reduction reactions and also takes place as a result of the oxidation reaction. Decreased levels of these metals may also occur because moringa amphoteric protein binds to the oppositely charged heavy metal ion-binding compounds, which causes the metal ions to precipitate. Alkaline pH generated by the addition of moringa also allows the positively charged metal ions to precipitate as insoluble metal hydroxides due to the release of OH groups of MSE. This is supported by the fact that in the treatment without coagulant, to precipitate the metal is done by applying a solution of alkali (e.g., lime) to form hydroxide precipitate of the metals. Precipitated metal will be more stable if the pH of water is above 10.5. This, of course, is not effective in the treatment of SW, DW, and GW because it will require an additional process to lower the pH value [67].

5 Plant Analysis Results

5.1 *Effect of Different Water Sources as Affected by Moringa Seed Extract on Yield and NPK Uptake of Lettuce Plants*

Data presented in Table 7 show that plant height; chlorophyll a and b; carotenoids; fresh and dry weight; and N, P, and K uptake of lettuce plants were clearly affected by the interaction between different sources and MSE. The highest values were observed in the treatment of sewage water in the presence of MSE, while the lowest one was obtained with drain water in absence of MSE. Fresh and dry weight yield of lettuce plants ranged from 575 to 761 and 96.01 to 180 g plant^{-1}, respectively. These results are in agreement with those obtained by Munirat et al. [77]. The beneficial effects of sewage water application may be due to the greater capacity of sewage to supply nutrients to the plant and to improve soil properties. These nutrients may activate the hydrolytic enzymes during planting, which in turn increase the amount of hydrolyzeates, e.g., glucose and amino acids, which are required for growth of embryo axes [78, 79].

Results showed that application of MSE to different water sources increased fresh and dry weight and N, P, and K uptake of lettuce plants compared to the untreated waters. These increases represent 3.5, 7.1, 16.1, 19.8, and 13.4% for WW, respectively; 8, 8.3, 19.1, 24.5, and 17.7% for DW, respectively; 9.5, 14.6, 34.0, 27.2, and 27.2%, respectively, for SW; and 4.9, 12.6, 20.9, 48.9, and 20.0%, respectively, for GW. These results are in agreement with those of [27, 78, 79].

The positive effects of irrigation with sewage water might be due to the increase in the nutrients of the soil under sewage water irrigation. These nutrients may improve the physical and nutrient contents of the soil, hence significantly increasing the total chlorophyll and carotene and establishing good growth and increased biomass and yield of the crop. This justification is supported by many independent studies [80, 81].

5.2 *Effect of Different Water Sources as Affected by Moringa Seed Extract on Heavy Metals Accumulation in Lettuce Plants*

Results presented in Table 8 show that different water sources treated with MSE significantly decrease heavy metals uptake of lettuce plants as compared to untreated water. This finding stands in agreement with those of [77, 78, 82].

Regarding the effect of different water sources, data indicate that the application of different water sources to soil, i.e., DW, SW, and GW, gave the higher values of heavy metals uptake of lettuce plants compared to well water. The main effect of water sources are as follows: SW $>$ DW $>$ GW $>$ WW. The highest values of Pb, Cd, Ni, Fe, Cu, Zn, and Mn uptake of lettuce plants were observed with application

Table 7 Effect of different water sources as affected by moringa seed extract on yield and NPK uptake of lettuce plants

Factor of study		Plant height, cm	mg g^{-1} f wt			g $plant^{-1}$		Nutrient uptake (mg $plant^{-1}$)		
			Chlorophyll a	Chlorophyll b	Carotenoids	Fresh weight	Dry weight	N	P	K
Effect of water source (a)										
WW		37.5b	1.32b	0.41b	0.45b	722b	145b	3197b	610b	2794b
DW		25.16d	1.07d	0.25d	0.24e	598d	100d	1862d	262c	1697d
SW		43.16a	1.44a	0.48d	0.56a	797a	168a	4334a	755a	3751a
GW		31.5b	1.23c	0.36c	0.34d	651c	126c	2003c	224d	1973c
Effect of MSE (b)										
Without		32.58b	1.20b	0.34b	0.37b	670b	128b	2544b	408b	2318b
With		36.08a	1.33a	0.41a	0.42a	714a	142a	3154a	517a	2789a
*Effect of interaction (a * b)*										
WW	Without	36.66d	1.30bc	0.39bc	0.43d	710d	140d	2959d	555c	2618d
	With	38.19c	1.33b	0.42b	0.46c	735c	150c	3435c	665b	2970c
DW	Without	23.33h	1.00e	0.21f	0.21f	575h	96.0h	1699h	233f	1559h
	With	27.13g	1.15de	0.30d	0.26ef	621g	104g	2024f	290d	1835f
SW	Without	41.32b	1.34b	0.41b	0.54b	761b	157b	3705b	665b	3302b
	With	45.15a	1.54a	0.55a	0.57a	833a	180a	4963a	846a	4200a
GW	Without	29.02f	1.18d	0.34e	0.31e	635f	119f	1814g	180g	1794g
	With	34.12e	1.29c	0.38c	0.37de	666e	134e	2193e	268e	2152e

WW well water, *DW* drain water, *SW* sewage water, *GW* groundwater, *MSE* moringa seed extract

Mean values in the same column for each trait followed by the same lowercase letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$

Table 8 Effect of different water sources as affected by moringa seed extract on heavy metals accumulation of lettuce plants

Factor of study		mg plant^{-1}						
		Pb	Cd	Ni	Fe	Cu	Zn	Mn
Effect of water source (a)								
WW		0.02d	0.44d	1.41d	41.32d	2.62d	42.55d	26.99d
DW		0.13b	1.38b	3.13b	112b	4.33b	132b	57.63b
SW		0.19a	2.17a	5.55a	167a	7.67a	181a	80.06a
GW		0.09c	1.01c	2.19c	90.16c	3.50c	90.24c	40.96c
Effect of MSE (b)								
Without		0.13a	1.56a	3.55a	110a	5.17a	130a	57.95a
With		0.09b	0.94b	2.59b	94.92b	3.89b	92.39b	44.87b
*Effect of interaction (a * b)*								
WW	Without	0.03f	0.53f	1.45g	43.63g	2.98g	45.29g	30.96g
	With	0.02f	0.35g	1.37gh	39.01h	2.26h	39.81h	23.01h
DW	Without	0.14b	1.69b	3.53c	119c	4.65c	145b	62.32c
	With	0.13c	1.06	2.73d	105d	4.02d	117d	52.94d
SW	Without	0.24a	2.79a	6.63a	178a	9.11a	218a	92.30a
	With	0.15b	1.54c	4.46b	156b	6.23b	143c	67.83b
GW	Without	0.11d	1.22d	2.59e	101de	3.95e	112e	46.22e
	With	0.07e	0.80e	1.80f	79.27f	3.05g	68.20f	35.69f

WW well water, *DW* drain water, *SW* sewage water, *GW* groundwater, *MSE* moringa seed extract
Mean values in the same column for each trait followed by the same lowercase letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$

of sewage water without MSE (0.24, 2.79, 6.63, 178, 9.11, 218, and 92.3 mg plant^{-1}, respectively), while the lowest ones (0.02, 0.35, 1.37, 39.0, 2.26, 39.8 and 23.0 mg plant^{-1}) were recorded from plants irrigated with well water treated with MSE.

From statistical analysis, results showed that addition of MSE to different water sources gave a significant decrease in Pb, Cd, Ni, Fe, Cu, Zn, and Mn uptake of lettuce plants compared to untreated water. These decreases represent 33, 34, 6, 11, 24, 12, and 25%, respectively, for WW; 7, 37, 23, 12, 14, 19, and 15, respectively, for DW; 38, 45, 33, 13, 32, 34, and 27, respectively, for SW; and 36, 34, 31, 22, 23, 39, and 23%, respectively, for GW. With sewage wastewater irrigation, concentrations of Fe, Mn, Zn, and Cu in all crops are optimal for wheat, bean, and onion growth, but those of Cd and Pb were high [77–79].

The plants grown in the soil irrigated with SW contained higher concentrations of heavy metals than those grown in soils irrigated with WW. The use of sewage wastewater in crop irrigation at the all six sites increased the uptake and accumulations of heavy metals in the plants. The concentrations observed in this study were higher than those reported by other workers [83–85] who have examined vegetation from heavy metal-contaminated sites. Concentrations of Fe, Mn, Zn, and Cu in the studied crops are within the acceptable limits for plant growth as well as consumption by humans and animals.

Data obtained reveal that in the SW-irrigated soils, all crops contained concentrations of heavy metals above the permissible levels for consumption by humans or animals [86].

6 Effect of Different Water Sources as Affected by Moringa Seed Extract on the Accumulation of Heavy Metals in the Soil After Harvesting

Results presented in Table 9 show that the soil irrigated with different water sources, i.e., DW, SW, and GW, without MSE contained higher concentrations of heavy metals than that soil irrigated with WW. This finding stands in agreement with those of [87]. The concentrations of Fe, Mn, Zn, Cu, Pb, Cd, and Ni are present at high levels in the soils irrigated with sewage wastewater relative to that irrigated with underground water [88].

Regarding the effect of different water sources, data indicate that the soil irrigated with DW, SW, and GW gave higher values of accumulated heavy metals compared to soil irrigated with well water. The main effect of water sources are as follows: SW > DW > GW > WW. The highest values of accumulated Pb, Cd, Ni, Fe, Cu,

Table 9 Effect of different water sources as affected by moringa seed extract on the accumulation of heavy metals in the soil after harvesting

Factor of study		mg kg^{-1}						
		Pb	Cd	Ni	Fe	Cu	Zn	Mn
Effect of water sources (a)								
WW		0.15d	0.05d	0.67d	1398d	1.11d	12.44d	142d
DW		1.06b	0.40b	1.11b	2151b	2.16b	51.92b	442b
SW		1.42a	0.59a	1.31a	3123a	2.36a	60.77a	596a
GW		0.79c	0.18c	0.86c	1914c	1.84c	33.55c	363c
Effect of MSE (b)								
Without		1.07a	0.44a	1.17a	2386a	2.09a	51.14a	487a
With		0.64b	0.17b	0.81b	1907b	1.64b	28.20b	285b
*Effect of Interaction (a * b)*								
WW	Without	0.18g	0.07f	0.76g	1540g	1.19f	14.52f	159g
	With	0.12gh	0.03g	0.57h	1256h	1.02f	10.37g	125h
DW	Without	1.33b	0.57b	1.35b	2312c	2.46b	64.03b	590b
	With	0.79e	0.24d	0.87e	1991e	1.86d	39.80d	293e
SW	Without	1.81a	0.88a	1.56a	3618a	2.71a	80.37a	702a
	With	1.02c	0.29c	1.06c	2627b	2.00c	41.17cd	490cd
GW	Without	0.96d	0.24d	1.00d	2073d	2.02c	45.63c	496c
	With	0.62f	0.12e	0.72ef	1754f	1.66e	21.47e	229f

WW well water, *DW* drain water, *SW* sewage water, *GW* groundwater, *MSE* moringa seed extract
Mean values in the same column for each trait followed by the same lowercase letter are not significantly different according to Duncan's multiple range test at $P \leq 0.05$

Zn, and Mn in soil were observed with application of sewage water without MSE (1.81, 0.88, 1.56, 3,618, 2.71, 80.3, and 702 mg kg^{-1}, respectively), while the lowest ones (0.12, 0.03, 0.57, 1,256, 1.02, 10.3, and 125 mg kg^{-1}) were recorded from soil irrigated with well water treated with MSE. Wastewater irrigation is considered as the primary major source of metal contamination in irrigated soils. Thus, it may contain various heavy metals such as Fe, Hg, Cd, Pb, Cu, Cr, Zn, Ni, and Mn, depending upon the type of activities it is associated with [78, 89].

From statistical analysis, results showed that the soil irrigated with different water sources with MSE gave a significant decrease in the accumulation of Pb, Cd, Ni, Fe, Cu, Zn, and Mn compared to the soil irrigated with different water sources without MSE. These decreases represent 33, 57, 25, 18,14, 29, and 21%, respectively, for WW; 41, 58, 36, 14, 24, 38, and 50, respectively, for DW; 44, 67, 32, 27, 26, 49, and 30, respectively, for SW; and 35, 50, 28 15, 18, 53, and 54%, respectively, for GW. This finding stands in agreement with those of [27, 90–92].

7 Conclusions

Concisely, *Moringa oleifera* seed extract is a potential source for water treatment due to its efficacy. When used for the treatment of wastewater, excellent results were obtained. The seeds are environmentally friendly because they do not further deteriorate the environment. Also, due to its availability and maximum effluent removal from both domestic and synthetic wastewater, the application of the seeds in wastewater treatment is undeniable. Results showed that the lowest values of SSP, SAR, SCAR, RSC, RSBC, PI, PS, KR, and MAR were observed in DW followed by GW, SW, and WW after treatment with MSE. MSE coagulant has better coagulation capability to reduce water turbidity, NO_3–N, BOD, COD, DO, and heavy metals compared with untreated water. The soil irrigated with different water sources after treatment with MSE gave a significant decrease in the accumulation of Pb, Cd, Ni, Fe, Cu, Zn, and Mn compared to the soil irrigated with different water sources before treatment with MSE. These decreases represent 33, 57, 25, 18, 14, 29, and 21%, respectively for WW; 41, 58, 36, 14, 24, 38, and 50, respectively, for DW; 44, 67, 32, 27, 26, 49, and 30, respectively, for SW; and 35, 50, 28, 15, 18, 53, and 54%, respectively, for GW.

8 Recommendations

Agriculture is the major consumer of water in Egypt, accounting for about 80–85% of the total net demand in the country. Because of Egypt's arid climate, nearly all agriculture depends on irrigation water. Any remaining water is used for municipal and industrial purposes, fish ponds, and other requirements. Since 1990, Egypt has been at the "water poverty line" with respect to its per capita share of water; it fell to almost 1,000 m^3/year. In 2011, however, this share decreased again to just about 700 m^3/capita/year and is expected to fall to 500 m^3/capita/year before 2030.

Population growth, and the essential need for horizontal expansion of the cultivated land, which is vital to feed Egypt's growing population and ensure social and political stability, will increase demand for irrigation water. Improving the use of its limited water resources, and saving considerable quantities of water to meet the needs of the horizontal expansion of the cultivated area, is a major challenge for Egypt.

The total area of cultivated land at present is about 3.61 million ha (8.6 million feddan) –2.73 million ha (6.5 million feddan) in the Nile Valley and Delta (old lands) and 0.88 million ha (2.1 million feddan) on the fringes of these regions in new lands reclaimed from the desert. Irrigated agriculture in Egypt is almost entirely dependent on Nile water – although there are minor contributions from groundwater. There is no significant rainfall except in a narrow strip along the north coast. At present, the average consumption of water for agriculture is about 58 billion m^3/year.

Expected increases in the consumption of water for domestic use, industry, and tourism will undoubtedly affect agriculture. To overcome this difficulty, agriculture has to come up with innovative ideas with respect to both cropping and irrigation systems. Although water is not treated as an economic commodity in Egypt, the country has to use water according to its value rather than its price. Crops are, therefore, cultivated according to their market value rather than local needs and consumption.

Food security has become an issue of prime political importance in Egypt, and potential agricultural expansion would increase pressure on the country's limited water resources. To meet increased food demand, two basic strategies are possible, importing food or growing more food with less water. Different agriculture projects have been established to enlarge the cultivated area and guarantee sufficient production of the country's main crops, issues that are considered top government priorities. Based on the concept of water reuse and increased efficiency, the use of scientific knowledge, international experience and cooperation, and advanced management tools should help in planning a sustainable future economy.

Sustainable agricultural development in the new lands demands care and understanding of the fragile desert ecosystem. Present threats to the sustainability of production systems are recognized in vast reclaimed areas of the country. These threats, which are mostly responsible for Egypt's food gap, include a shortage of water, low irrigation water quality, and poor management practices.

The role of clean water for achieving food and nutrition security for better human health cannot be underestimated. Water plays a great role in food and nutrition security through its linkage to all economic access to food: from agriculture through food preparations to nutrient bioavailability. Water turbidity removal is extremely important as it reduces problem associated with turbid water. Turbidity can effectively be removed by coagulation process which leads to sedimentation for easy separation.

Natural resources have been used in water treatment since ancient times but still need to be applied on a large scale. Presently there is increased interest in the use of plant materials as coagulants and disinfectants in water treatment.

Egypt is rich in biodiversity, and moringa tree can grow well, easy to find and easy to cultivate in various regions. Therefore, it is not difficult to use moringa seeds as a natural coagulant or biocoagulant for water clarifying process. The use of natural coagulants in water treatment process is expected to provide more advantages than the use of synthetic materials because they are natural and reported as safe to be consumed. The cost of using natural coagulants will be less expensive than that of alum. The effectiveness of natural coagulant for water purification will be tested also in the wastewater treatment process. Therefore, research should be conducted to find out the effectiveness of moringa seed in improving water quality. Water quality parameters that need to be investigated include turbidity, electrical conductivity, pH and temperature, metal absorbing capability, and ability to decrease microbial content.

Through this study, it is recommended to spread the use of moringa seeds in the purification of wastewater on a large scale and the work of large stations for water purification and water recycling in Egypt.

The Egyptian Government's present strategy for agricultural development until the year 2030 (SADS-2030) argues that the following themes are essential for agricultural development:

- Promoting agricultural growth through the efficient and environmentally sustainable management of land and water
- Technical options for maximizing water use efficiency, including water management options, crops, cropping patterns and varieties, and agronomic management
- Use of marginal-quality water for high productivity without degrading the land

Water management guidelines needed under conditions of water scarcity to produce more with less water.

Ensuring the sustainability of production systems under an increasing risk of salinization and land degradation

- Rationalizing the use of irrigation water and improving on-farm water management in the old lands
- Increasing new land reclamation, using water savings from the development of on-farm irrigation systems in the old lands
- Promoting private-sector activities in new land reclamation and water management

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Underutilized Plant Species and Agricultural Sustainability in Egypt

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Contents

Abstract Global agriculture is under pressure to produce a higher yield of food and feed. There are more than 50,000 edible plants in the world, yet two-thirds of global edible plant species is provided only by wheat, maize, and rice. Current reliance on commercial plant species and crops has inherent nutritional, ecological, and economic risks and is unsustainable in the long term. Wider utilization of underutilized plant species (UPSs) to agricultural systems is a good solution to this problem. Many UPSs are rich in bioactive compounds, vitamins, antioxidants, oils, and protein. UPSs could play an important role in the enhancement of nutrition, health,

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and income for local Egyptian communities. Also, UPSs are resilient in natural and agricultural conditions, making them a suitable surrogate to the major edible plants.

Egypt is one of the most populous countries. Most of Egyptians live near the Nile river, in an area of about 40,000 km^2, where the fertile area accounted for ca. 3.3 million ha, while one-quarter of which is reclaimed desert. Most land is cultivated at least twice a year, but salinity and drainage problems limit productivity. These challenges call for the need to sustainable agriculture (SA) in Egypt. Egypt is home to diverse agroecological areas which harbor many UPSs, whose genetic resources hold the potential to address SA and food security. The deterioration of food systems, lack of knowledge about the cultivation use and nutritional value of UPSs, changing food habits, and lack of attention to UPSs in policies are the key reasons for the abandoning of UPSs in Egypt. There is an urgent need to mainstream UPSs into Egyptian national programs and to integrate them into national food systems. This will improve the nutrition security of Egypt, biodiversity, and local economies. Development efforts and funding research on UPS breeding are needed to convert existing local landraces into competitive UPS varieties with commercial potential. This work will discuss important issues concerning SA in Egypt as well as the current and future situation of UPSs in Egypt.

Keywords Food security, Minor crops, Neglected crops, Sustainable crop production, Sustainable development

Abbreviations

GM	Genetically modified
SA	Sustainable agricultural
SCP	Sustainable crop production
SD	Sustainable development
UPSs	Underutilized (minor) plant species
WUE	Water-use efficiency

1 Introduction

By 2050 global population is expected to be 50% higher than at present wherein global grain demand is expected to be doubled. Sustaining food production performed by techniques that do not harm the environment and public health is a great challenge. There is a belief that agriculture can meet the food needs by sustainable means. Sustainability implies high yields and agricultural techniques that have acceptable environmental influence. Environmental effects of agriculture came from the conversion of natural ecosystems to agriculture, fertilizers that pollute water, and pesticides. Fertilizers and nutrients enter ecosystems through volatilization, leaching and the waste streams humans. Pesticides and pathogens associated with animal production practices are also harming human health [1].

Agriculture is under pressure to produce higher quantities of food for the anticipated 9 billion people on earth by 2050 [2–10]. It is considered that agricultural production must increase by 70% to cope with an estimated 40% increase in world population by 2050 [11]. Ninety percent of this growth is envisioned to result from enhanced crop intensity and higher crop yields, while the remainder must be produced on land not used for agricultural production. While this conservative estimate is the outcome of a 2009 expert consultation about national trends, another group forecasts a 100–110% increase in the global crop demand from 2005 to 2050 based on quantitative global trends in per capita demand that emphasize income-dependent food choices [2, 7].

The increasing interest in animal products is a major driver for greater demand for crops grown for animal feed [6, 12]. As an expansion of pastureland is difficult with limited agricultural land resources, livestock production might shift to more cereal intensive feeding technologies, thus further increasing global cereal feed demand well above the projections [2]. Also, there is evidence that the production of biofuels from crops is another driver for stronger competition for land, water, and energy sources that are very important for food production [7, 13].

Many countries fail to have adequate water source to maintain per capita food production from the irrigated land. Forty percent of crop yield comes from the 16% of irrigated land. Unless water use efficiency (WUE) is increased, greater agricultural production will require increased irrigation. Technologies such as drip irrigation can improve WUE and decrease salinization while maintaining yields. Cultivation of crops with high WUE and the development of crops with greater drought tolerance could also contribute to yield increase in water-limited environments [1].

Despite the recent improvement in agricultural productivity, the annual yield enhancement rate of major cereal crops is now showing signs of slowing down [4, 14]. Weather fluctuations caused by global climate change are likely to aggravate the situation, leading to increased stresses, such as a widespread infestation of diseases and insects on crops [15, 16].

The human population derives most of its calories from few crops, with only about 30 species providing 95% of the global food energy [17]. Over 7,000 known plant species are domesticated, suggesting that a large share of potential food sources is underutilized [18]. Recent agricultural developments are focusing on staples (wheat, maize, and rice) on which most of the world population was already dependent for food security [10, 19]. For these reasons, many edible plant species are nowadays considered minor, underutilized, or neglected and have joined a category of underutilized plant species (UPSs) [10]. Although a standard definition of UPSs does not exist, studies have described the features of UPSs and the overriding issues affecting the conservation and use of their genetic resources [10, 20, 21].

Egypt is home to diverse agroecological regions which harbor a high plant diversity [10]. Diversifying global food sources with UPSs could be a key to solve food and nutrition insecurity [7, 22]. The world should consume more UPSs to sustain food security [4, 5]. Some UPSs have features of higher infield stability, allowing them to cope with more dynamic environmental conditions [16, 22–24]. Moreover, some UPSs are well-adapted to the socioeconomics of their region as they are preferred by farmers and consumers [23, 25]. The need for UPSs becomes more important considering global health and diet trends [5].

2 Sustainability and Sustainable Development (SD)

As a new academic discipline, sustainability sciences were emerged [26]. Sustainability science is an emerging research field dealing with the interactions between natural and social systems meeting the needs of generations while substantially reducing poverty and conserving the planet's life support systems [26, 27].

Sustainability is the core element of research projects, government policies, and organizations worldwide. The results of several years of attempt to achieve sustainable agriculture (SA) have not been satisfactory. Despite some improvement, conventional agriculture is still the dominant paradigm. Sustainability, climate change, and replacing fossil fuels with renewable energy sources are challenges for agriculture. SA has emerged to address the challenges that are facing modern agriculture. Two broad paradigms of sustainability are identifiable: one supporting a systems-level reconstruction of agricultural practice to enhance biological activity and the other adopting a technological fix, in which new technologies can improve sustainability outcomes [26, 28].

Sustainable development (SD) is the development that meets the needs of the present without compromising the ability of next generations to meet their needs. If needs are to be met on a sustainable basis, the natural resources must be well managed. SD is also a development strategy that manages natural and human resources as well as financial and physical assets, to increase wealth and well-being [29, 30]. SD was considered as a path toward the aims of social justice and environmental protection. Kassas [31] mentioned that SD could be realized through three bases: (1) economic efficiency, (2) social equality, and (3) environmental conservation. It is the responsibility of the governmental organizations to implement programs aiming at the conservation of the natural resources [26, 31, 32].

The recent focus on sustainable food systems requires the integration of agroecosystems and associated biodiversity into overall biodiversity management schemes. Cultivation and biodiversity are the foundation of productive and sustainable food systems [33, 34]. Sustainability implies the use of sources at rates that do not exceed the capacity of the planet to regenerate them [7, 10]. Sustainable intensification can be considered as producing more outputs with more prudent use of all inputs while reducing environmental damage and building resilience, natural capital, and the flow of environmental services [7, 35]. Juma et al. [36] reported six sustainability measures for sustainable intensification of agriculture. These measures include (a) same or less land and water use, (b) minimized greenhouse gas emissions, (c) efficient use of inputs, (d) increased natural capital, (e) strengthened resilience, and (f) reduced environmental effects.

3 Sustainable Agriculture (SA) in Egypt

Agriculture is an activity performed to produce food and other materials by controlled utilization of plants and animals [28, 37, 38]. Sustainable agriculture (SA) was defined by Altieri [39] as a system, which aims to maintain production in the long term without degrading the resources, using low-input technologies that improve soil fertility, by enhancing biological pest control, maximizing recycling, and diversifying production. Sustainable farming is a system that maintains the resource, relies on a minimum of synthetic inputs, manages pests and diseases through internal regulating processes, and can recover from the human disturbance caused by agricultural practices [26, 39]. Lichtfouse et al. [40] defined SA as farming systems that are maintaining their productivity and benefit to society indefinitely.

SA technological and economic dimensions have tended to be privileged, while the social dimension has always been neglected. Therefore, SA has suffered from limited adoption [28]. There is a consensus on three basic features of SA: (1) maintenance of environmental quality, (2) stable plant and animal productivity, and (3) social acceptability. Yunlong and Smith [41] suggested that SA should be assessed from social acceptability, ecological soundness, and economic viability perspectives [26, 28].

The goal of SA is to maximize the net benefits that society receives from agricultural production and from ecosystem services. This will require higher crop yields, increased efficiency of nutrients and water use, judicious use of pesticides, and ecologically based management practices. Fundamental understanding of agroecology, biogeochemistry, and biotechnology that are linked directly to breeding programs can contribute to sustainability. SA will require that society rewards farmers and ranchers to produce food and ecosystem services. Therefore, SA must be a broadly based effort that helps assure equitable, sufficient, and stable flows of food and ecosystem services [1].

Many SA practices focus on growing food sustainably in ways suited to the environment, including:

– Rooftop farms: Production of food closer to communities by growing on rooftops and in small backyard plots
– Aquaponics: Raising aquatic animals in a symbiotic environment with hydroponically grown plants
– Agroforestry: An intercropping that involves growing trees and shrubs alongside crops
– Permaculture: An agricultural philosophy that combines agroforestry, intercropping, mulching, and rainwater catchment [42]

Egypt comprises an area of about 1 million km^2, made up as follows: Nile valley and delta (ca. 4%), Eastern desert area (ca. 22%), Western desert area (ca. 68%), and Sinai (ca. 6%). Most of Egypt area is under arid and hyper-arid conditions, of which a small portion representing about 3% is used in agricultural production. The main agroecological zones in Egypt are the Nile valley including the fertile alluvial land of middle and upper Egypt, where the main source of irrigation water is the Nile river. Also, Egyptian land suffers from variations of degradation, depending on the region and the inhabitants [26, 43].

According to water sources, agriculture production areas in Egypt are concentrated in:

1. Nile delta region, where the main source of irrigation is the Nile river. Together with Nile valley, the agriculture area in this zone consists of ca. 6.6 million acres.
2. Reclaimed desert areas, Northern coastal area, Sinai, Eastern desert, and Western desert where the source of irrigation is the groundwater.

Although the Nile river streams through the Egypt, water is regarded as a scarce source, due to the rapidly growing population and the wide desert in Egypt where the main water resource is the groundwater. The annual share of Nile water in Egypt is 55.5 billion m^3, accounting for 76.7% of the country's water resources, wherein desalinated seawater represents ca. 0.08%. Total groundwater plus treated groundwater is 20.65 billion m^3 annually (28% of available water resources), but it cannot be added to Egypt's share of water as it is a reused source [26, 44].

Pollution of waterways and groundwater caused by industry and waste disposal in Egypt is a problem that reduces water availability for use due to the limited water sources; illegal water intakes exacerbate the irrigation water shortages and violations in cultivating more than the allowable areas of high water consumptive crops (i.e., rice). Treated wastewater is expected to be the renewable water source for agriculture expansion, and the existing Egyptian code for treated wastewater reuse in agriculture will need to be implemented [26].

Egypt faces the challenge of closing the gap between its limited water sources and the increasing water demand. Declining Nile water availability with growing populations and increasing requirements for development is an important issue. The principal water management challenges in Egypt stem from the nature and quality of supply and demand management responses to water shortage. Table 1 shows the water demand in Egypt in 2017, demonstrating how those requirements will be met through tapping nontraditional water sources, including water savings and reuse possibilities [45]. There is a need to develop national programs for water sources management. The civil society has an important role to play in the areas of water conservation and SA through food security [26]. In Egypt, cultivation of new drought-resistant plant species which are suitable for arid and hyper-arid conditions is a great challenge.

In Egypt, agriculture is recognized as a way of life, crucial for socioeconomic development, and as an engine for growth. The contribution of the agriculture sector in Egypt exceeds 30% of employment. About 57% of the total population in Egypt lives in rural areas, where poverty prevails. There is a strong correlation

Table 1 Comparison between water sources and water demand (estimated water balance, km^3 $year^{-1}$) in Egypt for 2017 from the Ministry of Water Resources and Irrigation [26, 45]

	Water source		Water demand
Lake Nasser via high dam	55.5	Agriculture	63.6
Drainage reuse	11.4	Industry	18.7
Shallow ground water	8.4	Domestic	6.6
Waste water reuse	2.4	Evaporation	2.5
Rainfall	1.3	Navigation	0.2
Total	79.0	Fishery	0.6
Industrial water flushed back to system	17.8	Total	92.2
Domestic water flushed back to system (not including reuse)	2.6	Drainage to sea	9.5
Agricultural water flushed back to system (not including reuse)	1.9	Total water demand	101.7
Fishery water flushed back to system	0.4		
Total water sources	101.7		

between the reduction of poverty and economic growth as well as a strong link between poverty and food insecurity [46]. About 70% of food-insecure people live in rural areas, and a large share of those people depend on agriculture for their incomes and food supplies. Economic diversification starts at the farm household, wherein agricultural and nonagricultural development reinforces each other. Farm incomes account on average for ca. 25–40% of total rural income, agricultural-related off-farm incomes account for an additional 20–35%, and nonfarm revenues accounted for ca. 40% of rural household incomes [26].

The SD challenges facing Egypt include SA development, the impact of climate change on health, food security and rural poverty, the need for a national development plan, and improving irrigation efficiency [26]. Handoussa [46] reported on the key development challenges facing SA in Egypt. He mentioned that the link between SA, environmental, and rural development, food security, and reducing poverty are central issues for achieving development.

4 Sustainable Crop Production (SCP)

The need to feed a growing population is pressure on agricultural production, as is coping with an increasingly degraded environment and uncertainties resulting from global climate change and the need to adapt agricultural systems. SCP is a way of raising food production in an ecologically responsible manner. This includes adhering to agricultural production practices that do not harm the environment, which supports sustaining national communities, and that provide fair treatment to farmers and workers. SCP contrasts with agricultural production that relies on growing one crop in a large area of land, intensive use of fertilizers and pesticides, and other inputs that are damaging to farmers and workers, to the environment, and to communities. SCP practices could lead to higher production, with less need for environmentally harm inputs [42].

SCP intensification provides chances for optimizing crop yield, considering the range of sustainability aspects including potential and/or social, political, economic, and environmental effects. Recent trends would indicate that the incorporation of ecosystem management into agricultural practices can enhance crop yield. With a focus on environmental sustainability through an ecosystem approach, SCP intensification aims to maximize options for agricultural production intensification through the management of biodiversity and ecosystem services [47].

Sustainable crops are grown alternately from commercial, industrial crops. Sustainable crop farmers focus on guaranteeing that their farming practices can be sustained over time and do not cause undue damage to the environment. Different principles are involved in SCP including minimal pesticide utilize, multicopying, and soil health [42].

4.1 Sustainable Plant Species

Plant variety selection is an important item of SCP. Industrial operations select plant varieties for ease of mechanical harvest, yield, fast growth, and ability to be transported, rather than for nutritional value. The focus on mono-cropping and hybridization in industrial crop production has resulted in a loss of biodiversity and a decline in nutrients in many crops [42]. In the industrial crop production operations, genetically modified (GM) crops might be grown to allow greater utilization of herbicides or to conform to perceived consumer demand. Sustainable agriculture rejects GM crops due to their potential adverse environmental effects, the uncertainty of their healthfulness, and a large amount of inputs required for their production (e.g., herbicides and fertilizers). On the other hand, SCP does not eschew hybrid varietals; crop varieties are chosen primarily for taste, nutritional value, and environmental adaptability.

4.2 Sustainable Irrigation and Practicing Water Conservation

Over-irrigation causes soil salinization, which could lead to a decrease in yield. Also, aquifers applied for irrigation are depleting rapidly. SA water conservation practices include rainwater catchment, low-volume irrigation, and planting of drought-resistant crops or crops that have been bred for an environment [42].

4.3 Socioeconomic Factors in Sustainable Crop Production (SCP)

SCP entails environmental and socioeconomic responsibility, which involves supporting farm communities, ensuring fair treatment of farmers, and sustaining food systems. Farmers are usually subjected to harsh working conditions, including hard living conditions, exposure to pesticides, and low income. Sustainable farm managers strive to treat farmers justly, including paying a fair wage for work. Monoculture farms are economically vulnerable to crop loss and fluctuations in supply and demand. Diversifying farms through sustainable multicultural practices could help reduce this economic susceptibility. SCP aims to support the community by ensuring that money spent for farm inputs is distributed throughout the communities, through the maintenance of farmland, and by serving as an integral component of food systems [42].

5 Implementing Sustainable Practices

Farmer incentives are a central item facing SA. Farmers grow crops to feed their families or to sell in a market that is becoming increasingly competitive. Although some ecosystem services, such as control of agricultural pests, are of direct benefit to farmers, other ecosystem services might benefit the public but be of no direct benefit to farmers. Farmers need to rely on a rapidly expanding base of biological and agronomic knowledge that is specific to agroecosystems, soil types, and slopes. Making the right decisions at the farm level regarding input use efficiency, human health, and resource protection is becoming a knowledge-intensive task [1].

The earlier paradigm of science being improved then disseminated to farmers should be replaced by an active exchange of information among scientists and farmers. Scientists in developing countries who understand the ecosystems, human culture, and demands on local agricultural systems must be trained, promoted, and brought into the international scientific community. To make agricultural systems more sustainable, greater public and private investments in human resources are needed. Without adequate investments, yield gains and environmental protection may be insufficient for SA transition [1, 2].

6 Plants Diversification

Globally, only three crops (namely, wheat, rice, and maize) covered about 40% of arable land in 2011 and delivered about 50% of human calorie intake [48]. International seed companies focus on major crops to ensure high investments. The lower license fees paid to the self-pollinating wheat crop make this crop less attractive for breeders [49] and may lead to a concentration on only two out of the three dominating crops [2, 7].

Diversified agroecosystems could be achieved in various ways. These ways include:

1. Through intraspecific genetic diversity in monoculture systems.
2. Diversifying crop land by growing grass strips or vegetation banks between and alongside monocultures.
3. Increased structural diversity in monocultures by diversifying the plant age structure so that natural enemies have a temporal and spatial refuge.
4. Temporal diversity could be achieved by rotating cereal crops with nitrogen-fixing crops.
5. Crop diversification by growing compatible crop mixtures in the same field is reported to lead to climate change buffering and increased yield.
6. Growing crops and trees together provides spatial and temporal diversity.
7. Development of larger-scale diversified landscapes at the landscape level by integrating farmland with agroforestry and livestock [7, 50].

Integration of native perennial plant species such as trees and mixtures of multiple grassland species into the agroecosystem have major benefits: it could generate high amounts of biofuel feedstocks, increase soil carbon storage, as well as decrease nitrogen emissions [7, 51]. Bobojonov et al. [52] reported on the constraints for crop diversification in the Khorezm region (Uzbekistan), wherein about 70% of the area in this region is used for irrigated cotton and winter wheat under a state procurement mandate. They reported that the diversification into other crops like potato and sorghum bean could lead to SA in the irrigated areas by enhancing economic, ecological, and social conditions.

7 Underutilized Plant Species (UPSs)

Searching for new sources of oils, carbohydrates, and protein is increasing worldwide. In most of developing countries, these crops and products are being imported [53], reflecting an imbalance between production and needs. Due to low availability of agricultural inputs or limited purchasing power of farmers, any resources available are used for cultivation of profitable crops. There is a need for adapted plants and crops under low-input regimes. Moreover, the current cultivation of main oil crops (i.e., soybean and oil palm) is non-sustainable [54, 55]. Also, a drastic change in the common cultivation practices is needed to combat global warming and maintain agricultural productivity [56].

Of the thousands of plant species, only 120 are cultivated for human nutrition and only nine supplies over 75% of the global plant-derived energy. According to the state of the world's plant genetic resources for food and agriculture, only about 7,000 of total 30,000 plant species have been used in the history of humanity for food needs [57, 58]. Wheat, rice, and maize accounted for more than half of dietary and energy supply [48, 59, 60]. This implies that more than 100 edible plant species are neglected or underutilized for their nutritional value. The term "underutilized plant species (UPSs)" in this work refers to all edible plant species (a) that are locally abundant but internationally rare; (b) that are undervalued, that is, their current public and private value is below its potential; and (c) for which there is a lack of research and information. Nearly 40,000–100,000 plant species have been used for food, shelter, and drugs [61, 62]. Moreover, UPSs are plants to which little attention is paid or that are entirely ignored by agricultural researchers, plant breeders, and policymakers [58].

UPSs are not commercially traded as commodities. They are wild or semi-domesticated varieties and non-timber forest species adapted to environments [58, 63]. UPSs contribute to food security and serve as means of survival during drought, shocks, famine, and risks. They can also supplement nutritional requirements due to their high nutritional potential [62, 64]. Farmers have consumed UPSs to complement their diets during hunger periods, such as when major staple crops fail or in the aftermath of disasters [58, 65]. Nonetheless, many of UPSs, along with a wealth of traditional knowledge about their cultivation and use, are being lost [63].

Underutilized or minor crops are defined as traditional crops widely grown in the past but today falling into disuse, whose distribution, cultivation, and uses are poorly documented and have received little attention from policymakers and decisionmakers. The in situ conservation of native crops by rural families has not been given the recognition by research and governmental organizations. More efforts are needed to ensure that underutilized crops are no longer ignored by markets and researchers [66]. UPSs, which are part of a larger biodiversity portfolio, were once more popular but today are neglected by the people [60, 67]. These UPSs continued to be managed and collected in marginal localities because of their value [68]. It has been realized that UPSs might play an important role in nutrition security [69], as well as income improvement [60, 70]. Moreover, the diversification of agricultural production systems through the promotion of UPSs offers opportunities for strengthening the adaption, mitigation, and resilience of the natural and socioeconomic systems to climate change [71]. UPSs are more resilient to climate stresses than advanced cereals and cash crops [60]. Chivenge et al. [72] reported in their study from Sub-Saharan Africa that amaranth, pearl millet, and beans are more drought tolerant compared to commercial crops including rice, wheat, and maize.

Cereals and traditional crops are usually more susceptible and input intensive to crop failure, price shocks, and market forces than UPSs and, therefore, constitute an unacceptable risk for poor farmers. The genetic resources of these crops may be vital for SA [67] and adapting to climate change because many of these species are adapted to stressful environmental conditions [60, 67].

Wild and exotic fruits constitute important phytochemicals and bioactive compounds of traditional diets. However, many wild fruits are UPSs and seldom eaten. These wild fruits have profitable utility in terms of being a rich source of carbohydrates, proteins, fats, vitamins, minerals, and fibers [73]. Moreover, these fruits have high levels of bioactive compounds, such as flavonoids, antioxidants, phenolics, and carotenoids. Thus, these fruits could be better utilized in health promotion crusades [74]. Many of exotic fruits could be processed into value-added products like beverages, juices, pickles, jams, and nectars for international markets where the exotic character of such products, as well as their nutritional value, could be appreciated [75]. Also, wild fruit species are a good source of genetic diversity, which could be exploited to raise hybrid varieties of fruits with improved biotic and abiotic stress tolerance [74]. Efforts have been made to investigate different wild and exotic fruits and to dive into the nutritional aspects of these underutilized fruits [76–82].

8 Nutritional Importance of UPSs

Investing in nutrition security has many benefits for developing countries because it contributes to the achievement of other development goals related to agriculture, water, education, health, poverty alleviation, and gender development. Food patterns with a high diversity of food groups and a variety of items with a range of micro- and macronutrients are important to achieve nutrition security [83, 84]. Little was done to research on the nutritional values and traits of UPSs, which prevents them from realizing their importance [58, 85]. There are difficulties in knowledge, such as the cultivation requirements and importance of UPSs in the diets. Some UPSs have high medical importance. Some UPSs have also helped the national community to develop the value chain of those UPS and trained the local women to prepare some commercial products [60, 86].

By dint of high level of health-promoting compounds including antioxidants, carotenoids, and minerals, many UPSs may improve the macro- and micronutrient content in the human diets. UPSs are important for ensuring a supply of bio-nutrients to the human body, the deficiency of which may lead to stunting, wasting, and being underweight, as well as other health problems. However, UPS role in the nutrition security is not adequately understood, and they have not been mainstreamed into existing policies on nutrition [87]. UPSs that were an integral part of household food baskets in the past are gradually being replaced by commercial cereals (i.e., wheat and rice). These UPSs are rich in bioactive nutrients and are comparable to advanced cereals in terms of dietary energy and protein content [60, 88].

9 Challenges to Produce UPSs

Despite the potential of UPSs for nutrition security, these minor plants are not considered as primary food crops by farmers and policymakers. This part looks at the challenges that limit the global production and consumption of UPSs.

9.1 Local Food Systems and Agro-Diversity

Population growth, changing demand for food, and low market value are the factors triggering the preference for potential cereals and crops. Global forecasts of economic development, as well as population growth, indicated that there would be substantial increases in food demand [89]. Although the population has grown and food demand has increased, agricultural productivity has not greatly increased due to the degradation of resources [60, 86]. Farmers and governments prefer high-yielding crops and cereals, whereas market demand for advanced cereals is higher compared to the demand for UPSs. Farmers often receive advanced payments from intermediaries for cultivating conventional crops, which resulted in them abandoning UPS cultivation [90]. Low cultivation of UPSs has also led to a decline in the diversity of agriculture ecosystems and dietary patterns [60, 91].

UPSs can play an important role to improve nutrition security, especially of the poor people because these plant species are less expensive, rich in bioactive compounds, and good alternatives to expensive food items. Legumes, for example, are a rich protein source for the poor who cannot purchase meat and meat products [60]. Some factors affect people consumption behavior. However, changing lifestyles, globalization, and increased per capita income are the most prominent [60, 92]. Among the households with higher living standards, acceptability for UPSs is low, and younger generations prefer traditional cereals and instant food products. This had many implications regarding changes in food systems including the replacement of UPSs with traditional crops and instant food items [60].

Shively and Thapa [93] mentioned that UPSs are the main food for poor households. In the mountain areas of Pakistan, wheat and fine rice have largely replaced traditional cereals [94]. Consumer studies regarding the purchase and consumption of kale (*B. oleracea*) in Nairobi (Kenya) revealed that consumers are interested in nutritional, sensory, and safety attributes of kale products [95]. Many gourd species are of commercial value and thus can make a significant contribution to household income [7]. In Eastern Africa and Southeast Asia, selected traditional vegetables are becoming attractive food group for the wealthier population and are slowly moving out of the underutilized category into commercial items [96]. Changing food habits results in higher demand for advanced cereals and other food crops, encouraging farmers to replace UPSs with traditional crops and cereals [60].

9.2 Nutritional Knowledge

Knowledge is important to the conservation of most UPSs and agricultural ecosystems. Lack of knowledge and experience on the UPS cultivation and their use, as well as nutritional value, is a reason for the change in food habits and production systems [60, 72]. Due to the loss of knowledge, the current generation is not properly aware of how to cultivate UPS and their role in agro-diversity. Regarding nutritional value, consumers and farmers are not aware that UPSs are strong contributors to nutrition security [97] and that hidden hunger may be reached through increased consumption of these phytochemical-rich crops. In addition, nutrition policies and programs have not focused on creating awareness among people about the nutritional and health-promoting importance of UPSs [60].

9.3 Policy Constraints

The recent international policy and legal frameworks on biodiversity and plant genetic resources have provided limited funding for the conservation and sustainable use of UPS genetic resources [10]. Thus, the protection and promotion of traditional crops and cereals are not among the priorities of most governments [98]. Strategies for the promotion and support of UPSs are almost entirely missing in the existing food and nutrition security policies of developing countries. There is no institutional mechanism to help national communities to use the benefits from local agro-biodiversity or to provide market incentives for UPS producers. Policies regarding farm subsidies or food pricing do not consider conventional crops, and market policies rarely consider the nutritional and ecological value of UPSs [21, 60]. Food and Agriculture Organization's (FAO's) Global Plan of Action for Plant Genetic Resources for Food and Agriculture [59] emphasizes the importance of UPSs. However, UPSs have still not been mainstreamed in the global food and nutrition security agenda, which resulted in a negligible demand for these plants in the international market [21].

10 Mainstreaming UPSs for Sustainable Nutrition Security

UPSs could make an important contribution to nutrition security if they are mainstreamed into agriculture, food, and nutrition security policies and integrated into national food systems [99]. UPSs have high potential to improve rural economics and are climate-smart due to high resilience to water and heat stresses and less requirement of inputs. These UPSs are socially acceptable due to their presence in national food production systems and consumption patterns. In this era of commercialization, the integration of UPSs into national food systems is not so simple due to farmers' preference for high-value and high-yield plant species in response to market demand and the changing habits of consumers. There is a need to create an environment through policy instruments so that farmers and consumers may resume the cultivation and consumption of UPSs [60].

Table 2 summarizes the suggested framework of using UPSs in sustainable food and nutrition security. The most important step in supporting the integration of UPS into local food systems is to mainstream UPSs into agriculture, food, and nutrition programs [100]. UPSs should be given equal importance as cereals and commercial crops in the national policies [91]. Another important step is to document and

Table 2 Suggested framework of using UPSs in sustainable food and nutrition security [60]

Policy steps	Suggested action	Contribution of UPSs to nutrition security	Contribution of UPSs to food security and health	National benefits
Mainstream UPSs in the national programs	Integrate UPSs in the national food systems	Reduce the chances of growth problems in children	Increase of food supply	Improve biodiversity
Promote the use of knowledge on the cultivation and applications of UPSs		Reduce the prevalence of anemia and nutrients deficiency in children and women	Improve the diversity in available foods	Reduce agricultural investment
Provide of seeds and germplasm for UPSs		Reduce the prevalence of underweight women	Improve farmers and national income	Increase employment opportunities
Strength the institutional mechanisms (i.e., market facilities, and extension services)		Reduce the number of individuals with low body mass index	Improve physical access to food	Increase ecotourism
Create interest in cultivating of UPSs among farmers			Improve diversity in food intake	Increase the exportation of food and pharmaceutical products
Create awareness among people about the nutritional value and health-promoting potential of UPSs			Improve intake of micronutrients	Improve national income
Support national food value chains and establish a national food processing and pharmaceutical industry for UPSs			Reduce health hazards (UPSs require less fertilizers and pesticides)	
Link UPSs with tourism				
Link UPSs with school feeding programs				

promote existing knowledge, experience, and techniques to support UPS resurrection. An adequate supply of seeds, germplasm, and guidelines on production techniques could be provided to farmers. It is also important to provide incentives to farmers in the form of subsidized inputs and mechanisms to support UPS price. The provision of incentives will create interest among farmers to cultivate UPSs. Mechanisms for storage services, market facilities, and extension services are important in creating interest among farmers to cultivate UPSs. Also, to improve market demand for UPSs, there is a need to create awareness among people about the nutritional value of UPSs, wherein this awareness might be created through media and in schools [60].

A similar kind of awareness about supporting national food chains and establishing an industry for UPSs is important to improve national demand and improve chances for farmers to increase income. Supporting food chains and processing will improve farmers' interest to cultivate UPSs [101]. The integration of UPSs into food systems will be valuable for national ecosystems and national economies, while UPS cultivation could improve biodiversity and the environment [102]. Genetic resources in UPSs are vital for SA and adaptation to climate change [60, 90].

For consumers, supporting industry for UPSs will result in an increased number of food, nutraceutical and pharmaceutical products, which might turn out to be valuable substitutes for unhealthy foods. Strengthening national food systems by promoting UPSs will improve the stability of food supplies and reduce dependency on external foods. Tapping the potential of UPSs will also reduce the chances of migration as it will increase local employment opportunities due to the establishment of local food value chains and a national processing industry. Moreover, the potential for food exports will increase with UPS cultivation [60].

UPSs might also be linked with tourism, whereas national food systems may be promoted to attract tourists. Hotels and resorts may be guided to include foods prepared from UPSs. In addition, there is huge potential to link UPSs with school feeding programs, wherein governments might establish UPS procurement centers in the producing areas to supply food items prepared from UPSs for school feeding programs. It will benefit producers and school children to improve their income and nutrition status [60].

11 UPSs with Commercial Potential in Egypt

UPSs have the potential to make a substantial contribution to food and nutrition security, to protect against market disruptions and climate changes, and to lead to better ecosystem functions and services, thus enhancing sustainability [50]. Black cumin (*Nigella sativa*), coriander (*Coriandrum sativum*), sesame (*Sesamum indicum*), rapeseed (*Brassica napus*), oat (*Avena sativa*), peanut (*Arachis hypogaea*), cape gooseberry (*Physalis peruviana*), and prickly pear (*Opuntia ficus-indica*) are examples of UPSs that could be cultivated in Egypt with commercial importance. It is hard to find any data about the harvested area, yield, and production quality of the UPSs mentioned above in Egypt in the official website of FAO (http://www.fao.org/faostat/en/#data/QC). Table 3 summarizes the phytochemical composition, health-promoting traits, and commercial products of some UPSs that could be commercially cultivated in Egypt.

Table 3 Phytochemical compounds, health-promoting traits, anticipated commercial products of some UPSs in Egypt

UPSs	Phytochemicals and bioactive compounds	Health-promoting properties	Commercial products	References
Black cumin (*Nigella sativa*) 	Essential fatty acids, thymoquinone, phenolic compounds, tocols, fat soluble vitamins, phospholipids, carotenoids, fat soluble vitamins, and bioactive volatile compounds	Antihyperglycemic, antioxidant, anti-inflammatory, hepatoprotective, antigenotoxic, antimicrobial, antimutagenic, anticancer, anti-obesity, and antilipidemic	Cold-pressed seed oil, volatile seed oil, vegetable oil blends, seed extracts, pharmaceutical products, and cosmetics	Ramadan [76] and Ramadan et al. [78]
Cape gooseberry (*Physalis peruviana*) 	Fibers, phenolic compounds, minerals, tocols, carotenoids, water soluble vitamins, and bioactive volatile compounds	Antioxidant, anti-inflammatory, hepatoprotective, anti-obesity, and antilipidemic	Juices, beverages, jams, dried fruits, fruit seed oil, pharmaceuticals, nutraceuticals, and cosmetics	Ramadan and Moersel [81, 82], Ramadan [77], and Hassan et al. [103]
Prickly pear (*Opuntia ficus-indica*) 	Fibers, minerals, phenolics, tocols, carotenoids, water soluble vitamins, fat soluble vitamins, essential fatty acids, and essential amino acids	Antioxidant, anti-inflammatory, hepatoprotective, antigenotoxic, antimicrobial, antimutagenic, anticancer, anti-obesity, and antilipidemic	Beverages, juices, jams, nutraceuticals, dried fruits, fruit seed oil, pharmaceuticals, and cosmetics	Ramadan and Moersel [79, 81] and Hassanien and Moersel [104]

A wider use of UPSs would provide multiple options to build temporal heterogeneity into uniform crop systems, thus enhancing resilience to biotic and abiotic stress factors and ultimately leading to a sustainable supply of healthy food. Apart from their commercial, medicinal, and cultural value, UPSs are also considered important for sustainable food production as they reduce the impact of production systems on the environment. Many of UPSs are hardy adapted to specific marginal soil and climatic conditions and can be grown with minimal inputs [7, 105, 106]. Not all UPSs can easily be turned into commercial products. Significant research, breeding, and development efforts are needed to convert existing national landraces of promising UPSs into varieties with wide adaptation and commercial potential [7, 48].

12 Conclusion and Recommendations

In Egypt, agriculture is a major economic issue and created most of Egypt's wealth. Agriculture is an important issue as a national food source, for international trade, for the balance of payments, and for land and water use and as a basic raw material for industry. Egypt needs extensive research in the field of SA to expand food production because of its very limited arable land and water sources. The search for ways to achieve SA and natural resource management in Egypt requires changes in the traditional approach to the problem-solving.

UPSs have a promising nutritional value, but their role in the nutrition security is not fully understood; and they have not been mainstreamed in the Egyptian policies and programs for agriculture, food security, and nutrition. This will improve the nutrition security of Egypt and have positive impacts on biodiversity and Egyptian economy. The following items and steps could be suggested as a strategic framework for integrating UPSs into the Egyptian food system:

– Mainstream UPSs into Egyptian policies and programs: diversification away from reliance on traditional cereal crops and fruits should be considered. With its high nutritional value, UPSs could provide an answer to the food and nutritional security.
– Contributions through research and investment by international organizations, coupled with the existing Egyptian programs, present a promising future for UPSs and are likely to generate interest among the private sector.
– As UPSs are less dependent on fertilizers and pesticides, the chances of chemical-induced health hazards will also be decreased. Integrating UPSs into national food systems will reduce the climatic and economic risks associated with advanced cereals and commercial crops.
– UPSs have the potential to improve farmers' incomes and the overall food and nutrition security by offering diverse food production at affordable prices with fewer risks.
– Funding research and breeding programs of UPSs: genetic research on UPSs should focus on resolving the genetic diversity, determining the relationship between genotype and phenotype, and developing a consensus linkage map with several molecular markers. Application of molecular breeding approaches will aid UPS improvement programs.
– Ensure the availability of UPS seed and germplasm and provide incentives to farmers to cultivate UPSs.
– Document knowledge on UPSs: wider promotion and scientific publicity should spark interest and develop an overall awareness of UPS potential.
– Create institutional mechanisms (i.e., market facilities and extension services).
– Raise awareness about UPS nutritional value.
– Link UPSs with school feeding programs and tourism.
– Support local food chains and establish a national industry.

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Plant Biotechnology Status in Egypt

Khalid E.M. Sedeek

Contents

Abstract Hunger and malnutrition are important factors that hinder the development of any country. Farmers have used traditional methods to solve the problem, but do not seem to succeed. However, plant biotechnology has potentials for improving crop productivity and ensuring food security. Also, it significantly shortens the time required for the production of new cultivars with desirable characteristics. Egypt hosts one of the oldest agricultural civilizations in the world (Craig, The agriculture of

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Egypt. Oxford University Press, Oxford, 1993). Despite this, it faces the risk of food insecurity due to the increasing rate of population and not using the modern technology to increase crop productivity. Therefore, Egypt started one of the most advanced plant biotechnology programs in Africa in 1990 and launched the Agricultural Genetic Engineering Research Institute (AGERI). AGERI is engaged in cutting-edge projects in the field of biotic and abiotic stress resistance, genome mapping, and bioinformatics. AGERI successfully engineered several crops which include wheat, cotton, maize, potato, cucumber, squash, melon, and tomato. These crops are in the pipeline of commercialization due to the governmental hesitation toward commercialization of genetically modified crops.

Keywords AGERI, Biosafety, Egypt, GMO, Plant biotechnology

1 Introduction

In agriculture, there is an imperative need to improve crop plant productivity and quality [1]. Farmers have been improving wild plants for about 10,000 years ago by crossbreeding similar plants species to produce new varieties with desirable agronomic traits. This type of genetic modification has been successful and helped to improve crops through a selection of useful traits such as increased yield, disease and pest resistance, and drought and salt tolerance [2]. However, conventional breeding is a very tedious and expensive process and takes several generations to achieve the desired results. Thus, it is not the method that is able to keep pace with the growing demands for food and other plant products.

Plant phenotypic trait is controlled by a single gene or by a group of genes that are inherited and passed from one generation to the next [3, 4]. Due to the recent developments in the area of plant genetics, the majority of genes controlling the most important agronomic traits have been identified [5–7]. Moreover, the genetic engineering tools allowed the modification of the internal genes and the transfer of desirable gene(s) across species and genetically distant organisms. This has opened up the way toward crop improvement by developing transgenic plants with novel traits, such as built-in resistance, biotic and abiotic stresses tolerance, and improved nutritional values [8, 9].

Biotechnology has been the most rapidly adopted technology in the history of agriculture and continues to expand in the world. The first stable transgenic plant was produced in the early 1980s, and the first commercially released crop (tomato) was in 1995. Since then there has been a dramatic increase in biotech crop area. In 2016, the global planted area increased 109-fold and reached approximately 185.1 million hectares [10]. A total of 26 countries planted biotech crops in 2016 (19 developing and 7 industrial countries). The United States of America is the leader in hectarage planted with commercialized biotech crops since 1996; it planted 72.9 million hectares (39% of total global area) in 2016. Developing countries increasingly adopt biotech crops, and more than half of the global area (99.6 million hectares) is grown in those countries [10]. The biotech products

Table 1 AGERI's genetically modified crops

Crop	Trait	Gene utilized/strategy
Wheat	Drought resistance	HVA1
	Salt tolerance	mtlD
	Fungus resistance	Chitinase
Cotton	Insect resistance	Bt
Maize	Insect resistance	Bt
	Drought resistance	NPK1
	Vaccine production	HBsAg
Potato	Insect resistance	Bt gene
Tomato	Virus resistance	siRNA strategy
Cucurbits	Virus resistance	ZYMV-CT-CP
Strawberry	Virus resistance	Virus coat protein (Cp)

derived from this area are significantly contributing to the feeding of the immense increasing number of people in the world.

In 2016, the GM (soybean, maize, cotton, and canola) comprised the most amount of hectares in the world [10]. GM soybean accounted for the largest share (50%) of total GM crop cultivation, followed by maize (33%), cotton (12%), and canola (5%) [10].

In Egypt, the human population is approximately 95 million with an increasing rate reaches to 2.4% per year [11]. Egypt import about 40% of its total food needs. Traditional breeding is not the way that Egypt can rely on to increase food security. In contrary, biotechnology offers a better way to enhance crop productivity and therefore reduce the gap between food production and consumption [12, 13]. Egypt is one of the first African countries that consider plant biotechnology as a strategically significant tool for improving national food security and raising agricultural productivity. It started an ambitious program in plant biotechnology in the 1990s aiming to solve its agricultural constraints. Egyptian scientists, especially at AGERI, took the burden of solving the main Egyptian agriculture problems through biotechnology. They were working hard during the last 25 years to improve the crop characteristics and were successful in producing several genetically modified crops such as cotton, wheat, strawberry, potato, squash, melon, and tomato (Table 1). These crops are in the pipeline for commercialization, waiting for the Egyptian decision-makers for the commercialization release.

This chapter gives an overview of plant biotechnology and the current situation in Egypt regarding the use of the technology.

2 What Is Plant Biotechnology?

Plant biotechnology is a collection of scientific techniques used to improve plant performance by conferring pest and disease resistance, herbicide resistance, and abiotic stress tolerance (such as drought and salinity) and develop products with enhanced nutritional value or other health benefits. Scientists have developed ways to identify the gene (or genes) that may confer advantages on certain crops and introduce it into the plant genome to obtain a desired trait. The introduced gene may come from another plant species or from different organisms (animals, micro-organism, etc.). Therefore, biotechnology enables the improvements that are not possible with traditional crossing (crossing of related plant species alone). There are some methods for manipulating the plant genome by delivery of foreign genetic materials [14–16]. The most common three methods are (1) direct gene transfer using biolistic gene gun [16], (2) *Agrobacterium*-mediated gene transfer [17], and (3) protoplast direct transformation [16]. Recently, genome editing tools enabled the modification of the internal genome without the need of introducing foreign DNA [18–20].

2.1 Insect Resistance

Plants are always attacked by various types of insects searching for the host or food resources. Subsequently, the plants are severelly damaged leading to a significant reduction of the yield. The most common strategy used to kill insect pests is to apply chemical pesticides. However, chemicals are not the safe way of pest management, because they are harmful to humans and environment and may kill other beneficial insects [21–23]. In these circumstances, transgenic insect-resistant plants provide an effective solution for insect management and environmental protection. The genetically engineered plants exploit the naturally occurring bacterial poisons, enterotoxins. Bt protein (Cry protein) is one of the most common enterotoxins that is produced by the soil bacterium *Bacillus thuringiensis* (Bt) and kills a certain group of insects [24]. It is not harmful to humans or any other animals including flies, butterflies, silkworms, etc. The action of the protein begins once ingested by the targeted insect; it binds to specific receptors in the gut and interferes with the absorption of nutrients causing death [25, 26]. The first insect-resistant genes used for making insect-resistant crops were the *Cry* genes (Bt genes). Several crops have been engineered by *Cry* genes to produce their own Bt proteins such as corn, cotton, potatoes, rice, maize, wheat, tomatoes, soybeans, wheat, etc. [10]. They appeared on the market in the mid-1990s [27]. The Bt crops do not need to be sprayed with insecticides and were proven to be very effective in controlling insects. Also, the quality of Bt crop is perceived as superior to that of non-Bt because the level of fungi damage is lower. As an example, the *Fusarium* infection levels in Bt maize were five- to ten fold lower than those found in non-Bt maize [28]. This, in turn, leads to a safer food or feed products and higher yield compared to non-transgenic varieties [29, 30].

2.2 Disease Resistance

Plants are facing another deleterious enemy, pathogenic disease, that causes a significant reduction in productivity or complete loss of the crops and therefore financial crisis. The major pathogenic enemies are fungi, viruses, and bacteria. Their infection can spread very fast and complicate the controlling procedures. This problem is particularly important in developing countries where farmers do not have the economic capacity to apply expensive chemicals. In some cases, agrochemicals are not very effective, and the manual removal of infected plant individuals is not practical and very laborious. Scientists have discovered new methods that provide resistance to plant disease throughout genetic engineering tools. A large number of transgenic crops with increased resistance to various fungal diseases have shown proven successful to fight the attack of fungi such as tobacco, tomato, alfalfa, and rice [31, 32]. These plants were engineered to produce chitinase as a normal constituent exhibit increased resistance to infection by fungal pathogens. Chitinase is an enzyme that degrades chitin (the major constituent of fungal cell walls) and prevents further growth of the fungus. In the case of viruses, several plants were engineered with the virus coat protein cDNA [33]. This kind of internal vaccine has shown promising results in crops such as potatoes, tobacco, tomatoes, rice, papayas, etc. [34].

2.3 Herbicide Tolerance

One of the major problems in agriculture is the growth of unwanted herbs (weeds) along with the crop plants. The weeds compete with the crop plants for soil nutrients, water, and sunlight, and thus the crop yields significantly reduced. Farmers usually spray chemical herbicides to control weeds which harm the crop plants as well if they are not resistant to the herbicide. Plant biotechnology allows a safer way of controlling weeds by genetically engineering the crop plant to be insensitive to broad-spectrum herbicides [35]. This can be done by introducing a gene that encodes herbicide-degrading enzymes into the target plant. Herbicide-tolerant crops were one of the first GMOs appeared commercially on the market because it is a straightforward trait that involved only a single gene. Nowadays, there are several herbicide-tolerant crops in the market such as corn, soybeans, cotton, canola, sugar beets, and rice [36].

2.4 Enhanced Nutrition

Many people in the world rely mainly on a single crop as a source of energy and nutrient intake, for instance, rice in Asia, maize in Zambia, and cooking bananas in

Uganda. The problem is the single food does not contain all the necessary nutrients the body needs. As a result, the people suffer from the lack of a particular element in the diet such as vitamin or mineral. The solution to such problem is to eat a balanced diet that contains sufficient protein, vitamins, and minerals, besides fats and carbohydrates. Biotechnology provides an alternative solution, by genetically engineering crops to enhance their nutrition qualities (protein content, starch qualities, oil content, antioxidants, etc.). As an example, vitamin A deficiency is a major health problem in Southeast Asia and Africa; it is the world's leading cause of blindness [37], especially in young children. It is estimated that more than 500,000 children become blind every year due to the deficiency in vitamin A. This problem is chronic in many parts of the world that rely on polished white rice in their food. Swiss and German scientists come to a solution and successfully modified rice (golden rice) by introducing three genes that allow rice to produce beta-carotene which is converted to vitamin A in the human body [38]. The nutritious golden rice can save millions of people from the consequences of vitamin A deficiency. The Swiss-German team improved the golden rice again by adding additional genes that increased iron content, potentially reducing the incidence of iron deficiency that affects millions of people in the world.

2.5 Abiotic Stress Tolerance

Abiotic stresses such as drought, salinity, snow, temperature, etc. are major factors that influence plant growth and productivity [39]. Stresses trigger a series of morphological, physiological, biochemical, and molecular changes in plants. Subsequently, plants respond to these environmental factors by turning on a number of genes to increase the levels of several defensive metabolites. The metabolites include sugars and their derivatives (e.g., fructans, mannitol, trehalose), amino acids (e.g., proline, glycine, betaine), and proteins (e.g., heat-shock and antifreeze proteins) that confer a certain degree of protection against stresses. It has been estimated that abiotic stresses cause approximately 70% yield reduction of the world crops [40]. The problem is expanding due to the limitation of water resources and the effect of climate change [41]. Also, approximately 22% of the agricultural land is saline [42]. As a solution, crop plants can be genetically engineered to overexpress the genes responsible for the production of the defensive metabolites. A quite number of transgenic crops have been made for that purpose and have shown a better performance in the face of stresses [43].

3 Agriculture in Egypt

Egypt lies in the northeastern corner of Africa with an area of one million square kilometers. The population of the country is about 95 million with a growth rate of 2.4% per year; more than 29.2% works in the agricultural sector [11, 44]. Egypt is predominantly desert, arid and semiarid rangelands. The main source of water supply is the river Nile, the longest river in the world. The great majority of people live near the banks of the river Nile. Only 3.6% of the land, equivalent to approximately 3.6 million hectares, is devoted to agriculture [44], making it one of the world's lowest levels of cultivable land per capita. However, agriculture is considered a principal sector of the economy. It is contributing about 11.3% to the gross domestic product (GDP) [44]. Varieties of crops are grown in the country, such as wheat, rice, maize, sugarcane, beet, cotton, different types of vegetables, fruit trees, and medicinal plants. Many farmers grow double-planted crops to maximize the yields of the cultivated lands. Currently, greenhouse systems have also been introduced for producing new and high-value crops on reclaimed lands. Agricultural development in Egypt faces many threats which include climate change, growing population, water security, little or no use of modern farming technologies and farm mechanization, and the division of land into small farming units (Global Arab Network, 2009), in addition to the natural enemies that negatively affect the productivity of crops such as pests, weeds, and pathogens. The government has made a remarkable progress to enhance the agricultural sector by supporting farmers and the agricultural inputs, encouraging the new investments, and increasing the use of technology. Recently, the government has launched two great projects, the reclaiming of 1.5 million feddan in the desert and the building of 100,000 modern greenhouses to increase the per capita food consumption.

4 Status of Plant Biotechnology in Egypt

Egypt realizes the importance of plant biotechnology and producing genetically modified crops. The government aimed to use the biotechnology to improve food security and promote sustainable agricultural development. To meet the above goals, the government has set one of the most equipped biotechnology programs in Africa which started in 1990 as a funded project by the UNDP called the National Agricultural Genetic Engineering Laboratory (NAGEL). The program aimed to promote the transfer of the knowledge and the application of biotechnology and genetic engineering and create a professional staff of scientists in that field. Then many research centers and public and private universities started their program of biotechnology such as the Agricultural Research Center, the National Research Center, the Academy of Scientific Research and Technology, the Desert Research Center, the Water Research Center, Cairo University, Ain Shams University, and the University of Sadat City.

One of the well-established biotechnology institutes in Egypt is the Agricultural Genetic Engineering Research Institute (AGERI). It is one of the leading institutes of molecular biology and crop biotechnology not only in Egypt but also in Africa and Arabic peninsula. It was established in 1992 within the Agricultural Research Center (ARC) of the Egyptian Ministry of Agriculture and Land Reclamation. AGERI has highly diverse research groups of qualified scientists who learned

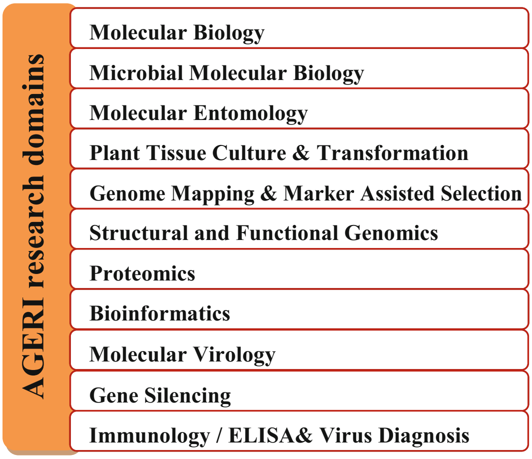

Fig. 1 Scientific research domains in AGERI

abroad at highly ranked institutions and universities. It focuses his research on the production of genetically modified crops and biotechnology-based products. AGERI's objective is enhancing the agricultural sector using the high-throughput tools in biotechnology to maximize the crop productivity. The institute is implementing a wide range of research to develop crops that are tolerant to abiotic stresses such as drought and salinity and resistant to biotic factors such as insects and diseases. Also, the institute is conducting many basic types of research on genome mapping, whole genome sequencing, and protein and biomolecular engineering (Fig. 1). AGERI has several collaborative research programs with local and international institutions and universities. It collaborates extensively with most of the ARC institutes such as the Field Crops Research Institute (FCRI), Cotton Research Institute (CRI), Horticultural Research Institute (HRI), and Plant Protection Research Institute (PPRI). AGERI has a research agreement with Michigan State University funded by USAID/Cairo under the National Agricultural Research Program (NARP). The aim of that collaboration is to improve insect resistance of some Egyptian crops and to establish a transformation system of maize, tomato, potato, and cucurbits. Some economically important crops have been successfully genetically engineered and are at the edge of commercializing; however, none of them have reached the market yet. Despite this, research is conducted on the following crops.

Here I am presenting some of the achievements of AGERI regarding GMO crop production.

4.1 Potato

Potato is the second most important vegetable crops after tomato in Egypt. It is cultivated continuously from August to June and is produced by 5.5 million tons annually over three seasons (winter, spring, and summer). It is considered one of the leading Egyptian vegetable exports to the European and Arabic market by 582,000 tons. The potato tuber moth, *Phthorimaea operculella* (Zeller), (PTM) is a notorious threat to potato fields and stored tubers that reduce potato quality and increase the potential for pathogen infection. It can damage the tuber in the field as well as in the storage state; the damage reaches up to 100% [45]. Therefore, a group of researchers from AGERI and Michigan State University (MSU) collaborated to to genetically engineer potatoes by Bt-cry5 transgene [42]. The transgenic tubers have been field-tested for seven seasons to test their resistance to potato tuber moth (PTM) in the International Potato Center (CIP) regional office in Egypt. The risk assessment requirements have been done; however, AGERI could not commercialize the transgenic potato due to IPR reasons. Another branch of potato research in AGERI is the development of potato varieties resistant to different viruses predominant in Egypt. The work focused on the production of virus-free stock sweet potato especially the local variety (Abees) resistant to sweet potato feathery mottle virus (SPFMV).

4.2 Cucurbits

Cucurbits are a large, diverse crop group that include a variety of high-value crops (e.g., melons, watermelon, cucumber, summer and winter squashes). They are an important part of a diverse and nutritious diet of Egyptians. The productivity and quality of Egyptian cucurbits are drastically affected by several viruses especially, zucchini yellow mosaic virus (ZYMV). The virus can cause 50–100% losses in the yield [46, 47]. A team of scientists from two institutes of the ARC [AGERI and the Horticultural Research Institute (HRI)] collaborated under the umbrella of the Agricultural Biotechnology Sustainable Productivity (ABSP) project. The overall goal of the team was producing high-quality cucurbits resistant to the major viral pathogen. They used the gene encoding the coat protein of the zucchini yellow mosaic virus (ZYMV), developed by the Michigan State University. The gene was transformed into the local squash cultivar, Escandarani; the local melon cultivar, Shahd El-Dokki; and the local cultivar, Beit Alpha via *Agrobacterium tumefaciens*-mediated transformation. The transgenic lines have been evaluated under the greenhouse and field conditions for several years. The majority of transformed plants appeared to be free of virus symptoms or developed high resistant (>92%) to ZYMV infection. The transgenic cucurbits have not been commercialized even after they approved by the National Biosafety Committee (NBC).

4.3 Tomato

Tomato yellow leaf curl virus (TYLCV) is one of the limiting factors for tomato production and can cause a complete loss in the yield. It has spread to all of the main vegetable-producing regions of Egypt and causes yield loss often ranging between 60 and 100%. To date, there are no reliable means for controlling or reducing the viral infection. Scientists from AGERI, Cairo University, and Donald Danforth Plant Science Center collaborated to genetically engineer tomato to induce resistance to geminivirus (TYLCV) [48]. They used the siRNA strategy to block the viral life cycle and to stop its spreading [49]. The modified tomato varieties that acquired resistance are of a good quality without the need for chemical sprays. The modified tomato varieties are in the stage of field trial testing, waiting for the approval from the NBC.

4.4 Maize

The maize research in AGERI has focused on the establishment of in vitro regeneration system of elite Egyptian maize inbred lines and optimization of maize transformation method using biolistic gene gun and different strains of *Agrobacterium*. There were several research projects which were carried out that aimed to improve maize resistance to biotic and abiotic stresses and the production of biopharmaceutical products. Examples of such projects are as follows:

1. The transformation of *Nicotiana* protein kinase (NPK1) gene into an elite Egyptian maize line to improve drought resistance. The expression of NPK1 showed an enhanced drought tolerance in the transgenic maize.
2. The development of Bt transgenic maize for resistance to corn borers as (*Sesamia cretica, Ostrinia nubilalis*, *Chilo agamemnon*) by the transformation of cry gene.
3. Another work has been carried out aiming to use maize as a bioreactor for vaccine production. The scientists successfully introduced the gene encoding the hepatitis B surface antigen (HBsAg) into maize.

4.5 Cotton

Egyptian cotton was known as one of the world's finest and is the country's most important agricultural export. AGERI and the Cotton Research Institute (CRI) [both are under the Agricultural Research Center (ARC)] have collaborated with Monsanto to develop an insect-resistant long staple GM cotton strain by crossing Egyptian elite germplasm with Monsanto's Bollgard II. The new variety expressing Cry1AC and Cry2Ab Bt genes confer resistance to cotton bollworms, pink bollworm and spiny bollworm, and cotton leafworm. The acquired resistance could save the cotton industry millions of dollars every year by boosting output and virtually eliminating chemical spraying. Also, the new variety retains the unique Egyptian cotton characteristics in every other aspect. After the approval by the NBC, field trials of the new long staple cotton varieties, namely, Giza 86, 89, 90, 91, and 96, have been carried out in May 2007 under the supervision of AGERI. In 2009, AGERI planted four transgenic cotton varieties (Giza 80, 85, 89, 90) to ensure the persistence of cry genes. The NBC granted the approval to the CRI to plant the GE cotton varieties to assess the yield and to multiply seeds. The seed multiplication was carried out at the ARC research stations in Giza, Seds, and El Gemiza. An assessment of the efficacy of *Bt* transgenic varieties against the insects in various locations and their effects on nontarget organisms was conducted in 2013. The varieties have shown resistance to insect infestations and do not affect the nontarget organisms; however, they are not approved yet for commercialization.

4.6 Wheat

Wheat is the most important crop in Egypt. It is cultivated in almost 1.23 million hectares with a total production of about 8.4 million tons/year. However, Egypt is still the world's largest wheat importer. It imported 12 million tons in 2017 due to the high rate of consumption. Therefore, increasing wheat production is considered a high priority in Egypt. There are many serious problems limiting wheat production as abiotic stresses especially drought and salinity. The wheat program at AGERI has focused on the establishment of regeneration systems and the improvement of abiotic resistance for Egyptian wheat cultivars. A group of scientists from AGERI and Ain Shams University were working together to transform immature embryos of Egyptian and American bread wheat with barley HVA1 and mannitol-1-phosphate dehydrogenase (mtlD) genes for drought and salt tolerance. The drought-tolerant lines were approved by the National Biosafety Committee (NBC) for field testing in 2009. The lines have been incorporated into the national wheat breeding program of ARC for further field testing and seed multiplication.

4.7 Others

There is a suite of other projects that were conducted in AGERI incorporating strawberry resistant to viruses transmitted by the whitefly using siRNA strategy, canola drought tolerant and Egyptian clover that is resistant to Egyptian cotton leafworm *Spodoptera littoralis*, and rice with improved starch characteristics and protein content.

5 Commercialization of GM Crops

Egypt is the first North African and Arab country that approves the cultivation of GM crops commercially. In 2008, Egypt first ever grew Bt maize called AgeebYG of 700 ha. Ageeb YG is an insect-resistant yellow hybrid maize, developed by Monsanto by crossing Bt maize (MON 810) with the maize variety Ageeb. It is resistant to corn borers, and it was distributed through an Egyptian private company called Fine Seeds. The company completed the required risk assessment and struggled for 10 years to receive the approvals. It was permitted to import 28 tons of the transgenic corn seeds. The GM corn was planted in four experimental sites (Sids in Kafr El-Sheikh, Nubaria, army farm at Cairo-Alexandria desert road, and El-Gharbia governorate). After intensive Bt maize field trial studies, the maize showed almost 100% protection from stem borers and 30–40% grain yield increase compared to the conventional yellow hybrid maize. Also, farmers were satisfied by reducing the input costs by reducing the amount of handling and the costly uses of harmful insecticides. At that time the Egyptian government was very interested to enhance their biotechnology program by growing more biotech crops for commercialization. This interest was reflected in ongoing research and thereby encouraged the Egyptian scientists to do field trials for some promising GM crops such as wheat, maize, cotton, potato, melon, banana, and tomato. It was planning to increase the hectarage of Bt maize in 2009 to reach 1,000 ha. However, the company was not successful to get the required license to import enough amount of the required seeds. Suddenly, the NBC suspended the importation of any transgenic seeds and did not allow the plantation of the locally produced transgenic plants until the biosafety framework is completed.

6 Development of Biosafety Regulation System in Egypt

Plant biotechnology applications are expanded quickly; many genetically modified plants have been released in the market. To eliminate the possible risks of such applications to human and environment, the biotechnology research should be carried out under the control of strict regulatory framework. Each country is required to develop its own biosafety regulations to control the growing and commercializing of the GM crops.

The Egyptian national biosafety system was established in 1995 by two ministerial decrees of the Ministry of Agriculture and Land Reclamation (MARL). Ministerial Decree No. 85 established the National Biosafety Committee (NBC) that includes representatives from several ministries (Agriculture and Land Reclamation, Education, Trade and Industry, Health and Population, Environment), the private sector, policymakers, and nontechnical members. The NBC has the power of setting regulations and guidelines concerning the safety of the genetic engineering and molecular biology approaches. The biosafety guidelines were set to regulate research field trials of GM crops, ensuring the safe use of their products. Ministerial Decree No. 136 established the obligation of having an advance permission from the NBC before dealing with genetically modified products. From that time, the NBC is considered the official office that is responsible for the formation and updating the biosafety guidelines, conducting the risk assessment, and issuing licenses.

Commercialization of GM crops is governed by another Ministerial Decree, No. 1648, issued in the year 1998 that established a protocol for the registration of genetically modified seeds. Accordingly, for GM varieties developed in Egypt, the applicant is required to provide detailed information about the GMO, including the genetic material introduced, the method employed, and evidence supporting a determination of no or little possible environmental risk. The applicant also is required to provide data showing the food and feed safety studies. In case that the GMO is approved in other countries, the applicant should provide the evidence that is released in the country of origin. After the NBC examines and considers the application, it is forwarded to the Seed Registration Committee (SRC) for preliminary approval to begin field trials. Three-year seasons of agronomic performance trails are to be conducted under the supervision of the SRC before the application granted final approval. If these are successful, an application is made with NBC authorization to the Seed Registration Committee for final approval. In contrary, the regulation of the importation of GM material is controlled by another committee under the Ministry of Health called the Supreme Committee for Food Safety (SCFS). By Ministerial Decree No. 242 of 1997, the Ministry of Health prohibits the import of any GMO foods without safety confirmation.

Egypt as most African countries ratified the Cartagena Protocol on Biosafety (CPB) in 2003. The CPB is an international agreement which regulates the movement of genetically modified organisms (GMOs) across borders. It aims to ensure the safe use of modern biotechnology products to human health, environment, and the biodiversity from possible adverse effects of that products. In 2012, the government suspended the commercial production, import registration, and cultivation of GM crops by the Ministerial Decree No. 378. In 2014, a new Ministerial Decree No. 1495 reestablished the National Biosafety Committee containing members from the Ministry of Environment (MoE), Ministry of Health (MoH), Ministry of Scientific Research (MoSR), and Ministry of Trade and Industry, legal advisor, and a representative of the Consumer Protection Agency [50]. In 2016, the Ministry of Environment (MoE) submitted the final version of the biosafety law to the Cabinet and to the Parliament for ratification.

7 Why Egypt Does Not Commercialize GM Crops

At the beginning of 1990, the Egyptian government was very motivated to introduce the field of biotechnology in agriculture. They believed that biotechnology is a promising way of overcoming some of the major challenges facing agricultural development in the country. They started a program to adopt the new technology to help to secure food. They initiated the Egyptian Biotechnology Information Center (EBIC) within AGERI to explain the benefits and potential risks of biotechnology and to simplify the information to reach to all levels of society. However, campaigns by media and environmental activists in the country against the adoption of biotech crops have created some obstacles to the development and adoption of GMO crops in Egypt. These campaigns successfully affected the public perception of the technology and created a public believe among Egyptians that the consumption of GMO crops and their derived products are not healthy and harmful in the long term. Also, some religious peoples from the major religions (Islam and Christianity) believe that changing the characteristics of a plant by way of genetic engineering is not allowed because it is considered an alteration of the creation of God. All of that creates further obstacles to the adoption of GMO in the country. Another important reason that forces the government to suspend the plantation and commercialization of GMO crops is the loss of the export market in Europe. On the contrary, Egypt imports some crops such as yellow corn and soybeans and their edible oil products from countries that openly grow and commercialize genetically engineered crops. We believe that these imported crops and products are sourced from GMOs or at least mixed with GMO crops. However, the policy of the Egyptian government is the imported food crops allowed as long as it is approved and consumed in the country of origin.

8 Conclusions

Biotechnology has been proven as a useful tool for agriculture practices. It can play a significant role in solving some of the challenges and constraints that face agriculture in Egypt. Egypt started an ambitious program in biotechnology in the early 1990s. At present, Egypt has well-established facilities and capacities for biotechnology and experts in the field of genetic engineering and production of transgenic crops, especially at AGERI. Also, Egypt has several transgenic plants produced by AGERI’s scientists waiting for the permission for the commercial release. Releasing such crops will improve the food quality and security in the country and will encourage investments in that sector.

9 Recommendations

As mentioned above, I recommend that the Egyptian government should take serious steps to exploit the benefits and take into their consideration the following:

1. Change policy toward the commercial release of GMOs.
2. Increase the research budget of that field.

3. Update the laboratories and research facilities.
4. Release the final functioning biosafety law.
5. Encourage national and international collaboration.
6. Support Egyptian scientists and fund their international training.
7. Encourage the involvement of private sector in GMO production.
8. Enhance the public awareness of biotechnology issues.

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Fermented Food in Egypt: A Sustainable Bio-preservation to Improve the Safety of Food

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Contents

Abstract The research in agricultural microbiology has experienced great changes in the past few decades, resulted in today's systematic farming that is a backbone of the economy all over the globe (Verma and Srivastav, Microorganisms in sustainable agriculture, food, and the environment. CRC Press, Taylor & Francis Group, Boca Raton, 2017). The production of fermented milk and cheeses made from raw milk of cows or other animals (cows, buffalo, camels, goat, and sheep) is an agri-food sector with high production volumes and product diversification in all the countries. Milk and dairy products play a role of primary importance in the diet of local consumers of all ages for the supply of essential nutrients such as high biological value proteins, vitamins, and minerals. These products also represent a resource for the economic sustenance of marginal areas and, for their high quality and genuineness, deserve a boost for expansion on a global scale market. Also, raw milk for direct consumption can be considered a typical product for countries, such as Egypt, where most consumers consider it safer than heat sanitized milk for a deeply

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rooted popular belief. Fresh milk in Egypt is mostly used to prepare traditional products such as cheese (White, Karish, Mish, and Ras), yogurt, Rayeb, Labneh, and butter. However, the many microbiological hazards and deterioration processes that can occur in raw milk and derived products pose a public health risk and determine a very short shelf-life of the product which is an obstacle for its distribution at longer distances. The effect of the implemented natural preservation on fermented products' compositional characteristics, the chapter will be focused on this point.

Keywords Bio-preservation, Egypt, Fermented food, Safety, Sustainable

1 Introduction

There are many different methods for preserving food to keep it sustainable, functional, and healthy, the oldest being drying followed by canning, pickling, and fermenting [1]. Advanced methods of maintaining food include cooling, freezing, pasteurizing, packaging, and supplementing artificial preservatives. Regrettably, modern methods use energy, produce greenhouse gases, create waste, and reduce the nutritional content of food [2]. In contrast, conventional methods of preserving food are sustainable, healthy, and can still be provided in the modern kitchen. Most ethical and modern food preservation techniques effect by inhibiting/killing the microorganisms in food. Food processing has always faced the challenge of reducing food's nutritional content since the most methods kill/inhibit the growth of microorganisms, including the beneficial microbes. Fermentation is unique in that the method increases the growth of microorganisms in the food. This process led to the food that would be full of living probiotics that will become a part of human intestinal ecosystem. Fermented foods are providing human bodies with the nutrients and probiotics that most other foods cannot [3]. Thus, fermentation is also a step towards sustainable living. Fermentation is one of the most essential food processing technologies and most ancient process all over the globe. Fermentation is a comparatively efficient, least energy conservation process, which raises the shelf-life and decreases the need for refrigeration or other forms of food preservation technology. From a biochemical point of view, fermentation is a metabolic process of obtaining energy from organic composites without the association with an exogenous oxidizing factor [4].

Significant advantages of fermentation technology in food regarded are: (1) Maintenaning of food through production of inhibitory metabolites such as organic acid (lactic acid, formic acid, acetic acid, and propionic acid), ethanol, bacteriocins, etc., often in combination with decrease of water activity (by drying or adding salt) [5]. (2) Improving food safety through inhibition of pathogens [6] or removal of toxic compounds [7]. (3) Improving the nutritional value [8]. (4) Organoleptic quality of the food [9, 10]. Recently, fermented foods are rising in universality (60% of the diet in industrialized nations) and, to guarantee the homogeneity, quality, and security of products, they are manufactured by the intentional utilization in raw foods with different microorganism cultures [11]. There is an updated inventory of microorganisms used in food fermentations including a wide range of foodstuff (dairy, meat, fish, vegetables, legumes, cereals, beverages, and vinegar). The International Dairy Federation (IDF) and the European Food and Feed Cultures Association (EFFCA) has confirmed a verifiable list of microorganisms with an authenticated use in food [12]. The list of starter cultures used in food was published in 2002 by Mogensen et al. [12, 13], while Bourdichon et al. [14] reported an updated taxonomy of the starter/protective cultures used in food fermentations to bring the taxonomy in agreement with the current standing in nomenclature. The IDF and EFFCA as well as additions found by searching the scientific literature for documentation of food fermentations with emphasis on microbial associations and food matrices were not originally included. From this, survey expanded list for each species to maintain only microbial species making desirable contributions to the food fermentation. The criteria chosen for including species on the list are: Inclusion – (1) Microbial species with a documented presence in fermented foods. Exclusion – (2) Lack of documentation for any desirable function in the fermentation process. (3) The species is a contaminant and/or does not harbor any relevant metabolic activity. (4) The species is unacceptable in food for scientifically documented reasons. Microorganisms awarding a health service to the host [15] are thus included if they are part of a culture used in a food fermentation process, whereas we have established not to include microbial species of probiotic strains only used in additions or over the counter products, as part of the manner of controlling the bacteria or yeast species used in food fermentations. Bio-preservation of foods means that the starter/protective cultures could be used to extend shelf-life and enhance the safety of foods [16]. Recently, supplementing fermented foods with bioactive molecules (i.e., cold pressed oil, and proteins/peptides) that resulted in prolonged shelf-life and improved the safety of raw milk and Egyptian dairy products could be called bio-preservation [17–21]. The chapter proposed here aims at selecting efficient methods of using natural and safe antimicrobials, namely, bacteriocins produced in situ and proteins/peptides from plants, to better protect raw milk from microbial contamination, prior to direct consumption or cheese making, by inhibiting pathogenic and spoilage bacteria.

2 Types of Egyptian Fermented Foods

There are many types of fermented foods in Egypt, i.e., lactic acid fermented milk cheeses (Karish, Mish, Ras etc.), yogurt, yogurt/wheat mixtures (Egyptian kishk), lactic acid fermented/leavened bread, and vegetable lactic acid fermentation (sauerkraut, cucumber pickles, and olives).

As the name designates, fermentates are fermented food components. These products may be manufactured from a variety of raw substances (typically milk, sugar, or plant-derived material), and the fermentation is done using food-grade microorganisms such as lactic acid bacteria (LAB) or propionic acid bacteria. The fermentation is produced to give a high yield of antimicrobial metabolites, which may include organic acids (lactic, acetic, or propionic acid), diacetyl, bacteriocins, and other secondary metabolites, depending on the characteristics of the strain(s) used for the fermentation. Fermentates are thus complex outcomes that inherently do not have a well-defined composition. Fermentates are usually provided as a dry, cell-free powder. The currently commercially available fermentates for use in foods are the Micro GARD range (DuPont) and the Dura Fresh range (Kerry). This involves the former Alta and Perlac products from Quest. There are various other products that are increasingly used as shelf-life extenders, namely, spray-dried vinegar or fermented wheat flour products. There are only limited scientific reports available on the functionality of fermentates in foods. The original Alta and Perlac were whey-based products for use as shelf-life extenders. The initial MicroGARD products, which were produced by fermenting skimmed milk or dextrose with *Propionibacterium shermanii* or specific lactococci, were explained to inhibit the psychotropic spoilage microorganisms and thereby enhance the shelf-life of cottage cheese [22]. Inhibition of *Pseudomonas*, *Salmonella*, *Yersinia*, and certain fungi was shown. Conversely, the MicroGARD and Alta products had no significant effect on aerobic mesophilic counts, e.g., *Escherichia coli* or *Brochothrix thermosphacta* when tested in an acidified chicken meat model stored at 22°C [23]. In hamburgers, the addition of 1% MicroGARD provided some initial reduction of *E. coli* O157:H7 and a bacteriostatic effect against *Listeria monocytogenes* during refrigerated storage [24].

2.1 Milk-Based Fermented Dairy Products

In Egypt, raw milk is consumed very commonly, and it is also given to infants. In most cases, it is supplied directly by many small dairy farmers who collect and transport it in conditions that often do not ensure hygiene and the cold chain since they cannot afford portable refrigeration to preserve the milk. To maintain the relative sterility of milk substances, formaldehyde and hydrogen peroxide are commonly added in usually uncalibrated amount. In 2009, the Egyptian Chamber of Food Industries estimated that this informal milk sector contributes up to 80% of the total milk industry (up to four billion liters per year) [25].

Egyptian cheeses (Karish, Mish, and Ras) and other dairy products such as yogurt, Rayeb, Labneh, and butter are made from raw milk [26]. Traditional Egyptian milk cheeses are produced locally by small traditional operates and are often produced on site by hand. There is also a high demand for traditional specialty dairy products, such as Ras and Domiati cheeses.

Milk-based fermented dairy products are widely produced in different agro-climatic zones for nutrition and income generation, varying according to sociocultural and taste preferences. Examples for Egyptian fermented milk (i.e., sour milk, Karish cheese, Mish cheese, Laban Zeer, Kishk, and Zabady) are popular ethnic fermented foods in Egypt [26]. Research on traditional fermented dairy products in Egypt has been mainly focused on the physicochemical properties, microbiology, and sensory evaluation and safety of different dairy products [27–29].

2.1.1 Sour Milk (Laban Ra Yeb or Laban Matrad and Butter Milk)

In Egypt, curdled milk specialty can be drunk fresh or can separate milk fat as butter to make the remainder into products, consumed as such or after storage, throughout the year. These products include Karish cheese, which itself is used to make Mish cheese. These products smell like buttermilk, slightly sour to taste. Egyptian farmers, mainly in Lower Egypt and partially in Upper Egypt, put fresh milk in earthenware pots (Matared) and leave it undisturbed in a warm place until the cream rises and the lower partially skimmed milk coagulates. This is called "Laban Rayeb" or Laban Matared." The cream layer is removed and whipped by hand to butter. The sour milk "Laban Rayeb" is consumed either as it is or after conversion to a soft acid cheese "Karish cheese." Both butter granules and sour milk are produced by this method. During hot weather, it is stored on successive days in earthenware containers named "Zeer" for preparation of Laban Zeer used for the Kishk making. The sour milk in Egypt has been examined chemically and microbiologically by Abd-El-Malek and Demerdash [30, 31].

2.1.2 Karish Cheese (Kartesh or Kareish)

Karish cheese is one of the most popular fresh cheeses made from sour milk, either Laban Rayeb or buttermilk or skimmed buffalo or cow milk in Egypt. It is a soft cheese containing about 70% moisture and not more than 10% fat. Skim milk, either fresh or slightly fermented, is also used on a commercial scale for its manufacture in small private dairy plants. The cheese is consumed fresh or after pickling for a long time in a pickling medium. The pickled cheese which has undergone extensive degradation of fat and protein is called "Mish cheese." Karish cheese and Mish cheese are an acid dairy product which is widely used in Middle Eastern countries. Current legislation in most countries prescribes animal welfare, milking and collection hygiene, and cold chain observation as measures to guarantee raw milk safety. These procedures could keep milk quality unaltered for a long time.

The first European directive issued on raw milk production, marketing, and transformation is the 92/46/EEC, that has been followed and amended by regulations 852/2004, 853/2004, 2073/2005, and 2074/2005 that allow the production of raw milk cheeses if certain requirements are met. Each European Union member state and Mediterranean Sea countries, i.e., Egypt, must follow these minimum regulations but can also establish stricter measures, and therefore an individual country can decide to ban the sale of raw milk and raw milk cheeses. Moreover, member states can allow exceptions regarding processing facilities and materials for the production of traditional cheeses.

The basic requirements established by the EU for producing raw milk cheeses include the use of milk that comes from animals that have no symptoms of infectious diseases. These diseases can be potentially transmitted to humans through milk (in particular it must come from farms officially free from brucellosis and tuberculosis). (1) Milk that has not been given unauthorized substances or products, and minimum suspension times must have been respected, (2) bacterial counts at 30°C below 100,000 bacteria per ml for cow's milk and 500,000 bacteria per ml for raw milk from other animals, and (3) processing within 2 h of milking or chilling below 8°C in case of daily milking or below 6°C when milking is not carried out daily (http://www.specialtyfood.com/news-trends/featured-articles/retail-operations/the-myths-about-raw-milk-cheese).

The processing facilities must allow proper maintenance, cleaning and/or disinfection, withdrawing or decreasing to any minimum air-borne contamination and ensuring a workspace that allows all services to be carried out in hygienic conditions (http://www.specialtyfood.com/news-trends/featured-articles/retail-operations/the-myths-about-raw-milk-cheese). However, dispensations are allowed for cases in which the environment contributes to the development of the cheese's characteristics so that the facilities can have walls, ceilings, and doors not made from smooth, impermeable, nonabsorbent, corrosion-resistant materials and also wooden cheese vats can still be used.

Businesses that produce milk and dairy products must be either registered or recognized; registration allows sales at a local level, while recognition allows sales to other retailers and abroad without geographical limitations. Recognition involves more frequent inspections by the health authorities.

2.1.3 Mish Cheese

Mish cheese is an important dairy food used by Egyptian farmers and used as an appetizer by the rest of the population. It has a yellowish-brown color, sharp flavor, and a very high salt content. It is made by pickling Karish cheese in a pickling medium in earthenware jars named Zallaa or Ballass and stored for ripening for a long time (more than 1 year) [32]. The pickling medium consists of buttermilk, Laban Rayeb, whey, and mourta which is a brown product that precipitates after the boiling of butter for the manufacture of butter oil and is named in Egypt "Samna." It consists of protein, fat, moisture, and salt. Spices (ground black pepper, cammon, and sharp-flavored red pepper), annatto, 6–15% salt, green pepper, and some old Mish as a natural starter are also added. Some makers put salts of borax, e.g., sodium borate at the top of the container as well as sharp red pepper and some spices tied in a piece of cloth with the purpose of killing *Pyophilla casei* larvae which may contaminate the cheese during preparation.

2.1.4 Laban Zeer

Laban Zeer is primarily a sour buttermilk (Laban Khad) collected and drained in an earthenware jar named Zeer in the house of farmers in the Upper Egypt. In hot weather, the coagulated Laban Khad which is not suitable for Karish cheese making because of its heavy bacterial load is normally stored in an earthenware container named Zeer. During storage, the whey percolates through the porous walls of Zeer, and the Laban Zeer becomes quite thick. On each addition of a new batch of sour milk, a suitable quantity of salt, judged by taste, is added to the contents of Zeer. The Laban Zeer is usually gathered from May to July to be used mainly in the making of Kishk, after mixing with prepared wheat grains [26]. It is also used for making a type of sour salad and a refreshing drink after being diluted with water.

2.1.5 Kishk

Kishk is a typical national food in Egypt, made of Laban Zeer and boiled, dried, and ground wheat grains. It is of good keeping quality and is consumed throughout the year in Egypt. It is a very popular food in Egypt, especially in Upper Egypt. It consists of small, round, or irregular pieces, yellowish brown, which have a rough surface and hard texture [26]. When moistened with water, it becomes white and breaks up after a short time.

2.1.6 Laban Zabady (Yogurt)

Zabady is considered to be the oldest fermented milk known in the world, especially in the area of Middle East. Zabady is the artisan type of yogurt manufactured in Egypt. Laban Zabady is produced locally by small traditional operators and is often produced on site by hand. Traditional yogurt made from buffalo's or cow's milk after pasteurizing and then adding starter cultures. Zabady is extremely smooth, white to off-white when prepared from cow milk, characteristic taste, and full, pleasant, slightly sour aroma.

2.1.7 Ras or Rumi Cheese

Rumi cheese is made from cow's or buffalo's milk or mixtures of them in Egypt. It comes from Kefalotyri (Kefali + tyri = head + cheese) [33]. It was introduced into Egypt by the Greeks. This type of cheese is made by adding starter cultures to pasteurized milk according to Litopoulou-Tzanetaki and Tzanetakis [33].

3 Microbial Hazards and Risks of Egyptian Fermented Foods

In Egypt, there is limited knowledge on the production of fermented foods especially raw milk cheese. Karish cheese is one of the most popular raw milk soft cheeses consumed in Egypt. It is an ancient type of white, soft, fresh lactic cheese made from curdled skimmed buffalo's or cow's milk. Similar to cottage and quark cheese, Karish cheese is made without the addition of rennet. However, neither LAB nor acidifying agents are added during manufacturing of Karish cheese. The increasing demand by Egyptian consumers for Karish cheese is attributed to its low price, palatable taste, and nutritional benefits. However, the discipline of food handlers in the manufacture of traditional raw milk cheeses performs a crucial role in restricting the hygienic status of the final product. Moreover, contamination of raw milk by enterococci of bovine fecal origin during the milking process or from environmental sources (such as milking equipment or contaminated water) is a relevant factor in the microbial contamination of raw milk cheeses [34]. It is noteworthy that *Enterococcus* spp. are also predominant pathogens causing bovine mastitis, which affects udder health and milk quality [35]. Consequently, contamination of fresh milk cheeses with animal, personal, or environmental enterococcal strains through different steps of processing is likely to occur. This depends on the sanitary practices involved throughout processing.

Regarding raw milk cheeses, it is necessary to guarantee the following microbiological criteria: absence of *L. monocytogenes* at numbers exceeding 100 CFU/g, the absence of *Salmonella* spp., the absence of staphylococcal enterotoxins, and low numbers of hygiene indicators like coliforms. The label must clearly indicate "made with raw milk." The commercialization of raw milk and dairy products made from raw milk in some North African countries is not allowed in European countries for sanitary concerns [36]. South African legislation on raw milk has similarities with the European one. Among other microbiological hazards, *Mycobacterium bovis*, which in a study carried out in 2009 was found to infect 30% of dairy cattle and 40% of farm workers, represents a risk [37].

Ombarak et al. [38], in a first comprehensive study regarding the prevalence and pathogenic potential of *E. coli* in dairy products in Egypt, found that raw milk, Karish cheese, and Ras cheese are highly contaminated with *E. coli*, including potentially pathogenic strains which may pose a public health threat.

Raw milk is considered at high risk of causing illnesses, based on the latest surveillance data published by the Center of Disease Control and Prevention [39]. A quantitative risk assessment, carried out to determine consumer risk from *Staphylococcus aureus* and staphylococcal enterotoxin in raw milk in California. *S. aureus* levels above the 10^5 CFU/ml level are concern and enterotoxin A production may represent a potential risk of staphylococcal enterotoxin intoxication in all consumer age groups [40].

Samples did not comply with the acceptability levels fixed by European regulations for *S. aureus* and *E. coli* in 4% and 44% cases respectively, thus indicating poor husbandry and poor hygiene practices during milk collection or preservation or during cheese production processes and handling that could be common to similar artisanal products. A correlation was also found between poor microbiological quality and some selling parameters [41].

Regarding safety evaluation for raw milk cheeses, Oliver et al. [42] reported that a recent example of how some traditional fermented products can pose health risks. Raw milk and cheese made from raw milk can be a major source of potentially harmful bacteria to human, such as pathogenic *E. coli* [42]. Consequently, foodborne disease outbreaks from consumption of raw milk and raw milk products resulted in public health hazard over all the world [42–44]. *Pseudomonas fluorescens* and *Pseudomonas fluorescent* group-related strains predominated (*ca* 86%) in the Gram negative psychrotrophic microflora were found in fermented foods. *Leuconostoc dextranicum* was the most frequent Gram positive psychrotrophic species isolated from dairy products [45]. Although raw milk and raw milk products have caused many illnesses and even deaths [46], their marketing and consumption widely exist in many countries including Egypt [47, 48]. Raw milk for direct consumption can be considered a typical product in Egypt, where most consumers consider it safer than heat sanitized milk for a deeply rooted popular belief. In this country, raw milk is consumed especially in some rural areas and used to prepare cheese, known as Karish and Ras cheese. Ras cheese is the most popular hard cheese in Egypt, and it is manufactured in a high proportion under artisan conditions and may be contaminated with a variety of microorganisms from different sources [42]. This chapter emphasized the necessity to improve production hygiene of fermented food. Especially the food chain of dairy products from raw milk, in line with the traditional cheese-making procedures. Also, we need to introduce new practices to improve safety that can be easily introduced in small producing plants and in rural areas. Whereas, the acquisition of adequate knowledge on safety issues by small artisanal producers is particularly difficult for integrated sustainable development in developing countries.

The different studies examining the microbiological quality of raw milk cheeses established the difficulties in achieving safe raw milk cheeses for consumption in many countries all over the world [49]. Within the genus *Enterococcus*, two species, *Enterococcus faecalis*, and *Enterococcus faecium*, have emerged as opportunistic pathogens and are responsible for an increasing percentage of nosocomial infections, including bacteremia and intra-abdominal and urinary tract infections [50]. Both species are intrinsically resistant to many antibiotics, including cephalosporins, lincosamides, penicillins and low levels of aminoglycosides. Importantly, the increasing levels of acquired resistance to multiple drugs in *E. faecalis* and *E. faecium* constitute a potentially huge public health threat as the therapeutic options become limited. When ampicillin resistance is present, clinical therapy usually involves antibiotics that are much more expensive and have more adverse side effects (e.g., linezolid, vancomycin, and quinupristin/dalfopristin) [51]. The development of hospital-acquired multidrug-resistant *E. faecium* strains from *E. faecium* of animal origin has been interpreted [52] and shows that *E. faecium* of animal origin can play as a donor of antibiotic resistance genes to other pathogenic enterococci. The virulence of *E. faecalis* and *E. faecium* is associated with several genes, including agg (aggregative pheromone-inducing adherence to extra-matrix protein), esp. (enterococcal surface protein), hyl (hyaluronidase), and gelE (gelatinase) [53, 54]. Interestingly, *E. faecalis* of animal origin, food of animal origin and human feces are highly similar concerning resistance pattern, virulence gene profile and pulsed-field gel electrophoresis (PFGE) types [55, 56]. Accordingly, *E. faecalis* from food of animal origin is a likely human hazard. However, enterococci are very much able to exchange genetic material, including antibiotic resistance and virulence genes, between themselves and with other genera using plasmids and transposons [57].

The prevalence of antibiotic-resistant enterococci isolated from humans has been shown using an antibiotic susceptibility test in Egypt [58, 59]. Nevertheless, there is little knowledge about antibiotic resistance, virulence factors and conjugative transposons of enterococci present in raw milk cheese in Egypt. Therefore, to increase our understanding of the molecular ecology of antibiotic resistance and virulence in *Enterococcus* spp. and other pathogenic bacteria. The fresh raw milk cheese, Karish cheese, is a potential reservoir of antibiotic-resistant and virulent enterococci that may constitute a public health hazard [27, 28].

Among other microbiological hazards, *Mycobacterium bovis*, which in a study carried out in 2009 was found to infect 30% of dairy cattle and 40% of farm workers, represents a risk [37]. Also, Ombarak et al. [38] in a first comprehensive study regarding the prevalence and pathogenic potential of *E. coli* in dairy products in Egypt found that raw milk, Karish cheese, and Ras cheese are highly contaminated with *E. coli*, including potentially pathogenic strains which may pose a public health threat. Raw milk is considered at high risk of causing illnesses, based on the latest surveillance data published by the Center of Disease Control and Prevention [39]. The level of *S. aureus* in raw milk collected by the University of California-Davis Dairy Food Safety Laboratory from 2,336 California dairies from 2005 to 2008 and using U.S. milk consumption data from the National Health and Nutrition Examination Survey of 2003 and 2004 could surpass the 10^5 CFU/mL level of concern. Therefore, this level may represent a potential consumer risk. It could represent a dose of the staphylococcal enterotoxin A production that is capable of eliciting staphylococcal enterotoxin intoxication in all consumer age groups.

Risks associated with fermenting and contaminating microorganisms need to be assessed as well. Some traditional Egyptian fermented foods might pose a health risk due to the concentration of biogenic amines, especially histamine [60]. Examples of these foods are fermented dairy products (blue cheese and Mesh cheese), fermented meats (fermented sausage), and fermented fish (salted fermented fish [Feseekh]). Egyptian fermented sausage had the highest concentration of total biogenic amines (2,482 mg/kg), followed by Mish cheese (2,118 mg/kg) and blue cheese (2,084 mg/kg). Feseekh was contained at a high level of histamine (521 mg/kg) and tyramine (2,010 mg/kg) in blue cheese. Biogenic amines also can be found in a variety of fermented foods and beverages, particularly protein-rich foods such as fish and fish products, meat and meat products, cheeses, and soybean products and beers [61]. These amines are usually formed by microbe-mediated decarboxylation of free amino acids [61]. However, several common LAB (e.g., *Lactobacillus* spp., *Pediococcus* spp., and *Streptococcus* spp.) are producing histamine [62]. In addition, a few foodborne pathogens (e.g., *Clostridium* spp., *Klebsiella* spp., *E. coli*, *Pseudomonas* spp., and *Shigella* spp.) are able to produce histamine. The histamine reached to hazardous levels in short periods when protein-rich food is kept at relatively high temperatures [62]. Unfortunately, once biogenic amines are formed, their concentrations are not reduced significantly even by high-temperature processing [63].

4 Bioactive Proteins/Peptides from Starter/Protective Cultures and Fermentation

Fermentation is a comparatively productive, low energy preservation method, which increases the shelf-life and decreases the need for chilling or other forms of food preservation technology [11]. Fermented foods are produced by the intentional application in raw foods (i.e., raw milk) in different microbial systems (starter/ protective cultures) [11]. Bio-preservation extended the shelf-life and enhanced the safety of foods using microbial cultures and/or their metabolites [5]. LAB is one of the generally employed bio-preservatives in different traditional fermented foods because it significantly contributes to the flavor, texture, and, in many cases, to the nutritional and functional values of the food products [64]. The LAB is playing as autochthonous or selected starters in food fermentation process. The LAB exerts the antimicrobial agents as a result of different metabolic processes (lactose metabolism, proteolytic enzymes, citrate uptake, bacteriophage resistance, bacteriocin production, polysaccharide biosynthesis, metal-ion resistance, and antibiotic resistance; [65, 66]). The LAB performs a key role in food fermentations. LAB contributes to the improvement of the desired sensory properties and keeps microbial safety in the final product. LAB has been recognized as safe (GRAS) status) and “it has been estimated that 25% of the European diet and 60% of the diet in many developing countries consists of fermented foods” [67].

The most immediate possibility is that of adding bacteriocinogenic cultures of bacterial species with a Qualified Presumption of Safety (QPS) status according to the updated list held by EFSA [68]. Accordingly, among the milk associated LAB, enterococci that did not receive a QPS status cannot be considered for use in food products without previous authorization based on the absence of hazardous traits.

Bacteriocins are a diverse group of peptides with antimicrobial activity. Four main classes can be distinguished, i.e., class I, or lantibiotics, that have low molecular mass and contain modified amino acids (lanthionine, ß-methyl lanthionine, dehydroalanine, and dehydrobutyrin). The class II, or small peptides called anti-listerial bacteriocins, are further divided into class IIa (cystibiotics), class IIb (two-component), and class IIc (multi-component). However, class III or bacteriolysins are heat-labile and have high molecular weight. The class IV are very stable circular peptides with a peptide bond between the C– and N– extremities. The first two classes comprise most bacteriocins produced by LAB and class I comprises nisin, the only bacteriocin currently authorized as a food additive in purified preparations in the USA and Europe. Bacteriocins can have narrow or broad inhibitory spectra, and variability on this respect exists even between variants of the same bacteriocin. The antimicrobial efficacy varies with the target strain, with the level of expression, and with the stability in food matrices. The effects of addition of bacteriocinogenic cultures to increase the safety of raw milk and raw milk cheeses have often been suggested but little explored. The quality and safety of raw milk and soft cheese are supporting potential associations between microbial cultures, and also the detection of LAB with antagonistic activity against foodborne pathogens [69]. Also, he indicated the antimicrobial potential of the autochthonous microbiota of raw milk and soft cheese against *L. monocytogenes* and *S. aureus* and suggested to isolate and properly characterize autochthonous LAB as antagonistic cultures to be used in conservation studies for pathogen control [69]. Among bacteriocinogenic isolates from cheese made with natural cultures, particularly interesting strains able to produce multiple bacteriocins were described [70, 71]. However, only a few studies considered the application of bacteriocinogenic cultures, singularly or in association to increase the antimicrobial potential in raw milk and cheese.

In most studies, the bacteriocin producers were examined in fresh food and not tested against bacteria with preeminent roles in cheese ripening, so that this aspect has still to be defined. Regarding this aspect, a recently published study carried out with a nisin a *Lactococcus lactis* subsp. *lactis* producer and an *Lactobacillus plantarum* indicator strain put in evidence that use of bacteriocinogenic bacteria can be done such that not to inhibit non-starter LAB and allow their growth in cheese for proper ripening [72]. These results obtained by using a nisin producer are particularly interesting since this bacteriocin possesses a strong antibacterial activity against many pathogens, including *L. monocytogenes*, *S. aureus*, and *Mycobacterium* spp., and also, it inhibits the sporulation of *Bacillus* and *Clostridium* [73]. Moreover, nisin was active in vitro against *E. coli* TG1 [74]. The overall effect of a nisin producer on cheese microbiota recently reported was a significant decrease in coagulase-positive cocci and, interestingly, the microorganisms of the same cheese performed a higher number of species compared to a cheese to which a nisin producer was not supplemented with products [75, 76]. Significantly lower amounts of tyramine, maintained at acceptable levels for human consumption, were found in the cheese inoculated with the nisin producer [77].

Recently, the application of producers of different bacteriocins in milk or cheese proved them useful for particular aspects. The bacteriocins are responsible for the formation of aroma compounds favored by SLAB lysis and inhibition of the adventitious NSLAB. However, microbiota are allowing to obtain fermented products with homogenous quality and production of volatile compounds (VOCs), inhibition of the late blowing agent *Clostridium tyrobutyricum* responsible for defects in semihard and hard cheeses, and inhibition of tyraminogenic microbiota [75, 76]. It is noteworthy that also an antiviral role against the herpes simplex virus was reported for a pediocin PA1-AcH-like bacteriocin [78], indicating the opportunity to further investigate the possibility to fight with bacteriocins against viruses that cause human diseases associated to raw milk consumption. Other proteinaceous molecules with antimicrobial function are some bioactive proteins, i.e., specific protein fragments that positively impact bodily functions or conditions, that can be obtained from various food protein sources.

5 Bioactive Proteins/Peptides from Legume Plants and Fermentation

The antimicrobial treatments that inhibit undesired microorganisms and not to extensively alter the composition and chemical parameters of traditional fermented foods are new trends in this field that confirm the advantages of the application of natural bioactive molecules in the food chain. Therefore, the addition of natural antimicrobials which can be easily accepted by consumers and by health control authorities and with effects that can last longer should be pursued.

The benefits of plant peptides to human health are known as antibiosis, a reduction in blood pressure, a reduction in blood cholesterol level, antithrombosis and antioxidation, the enhanced absorption of trace minerals, cytoimmunomodulation, and opioid activity. Inspection of crop proteomic data revealed that at least 6,000 proteins could harbor bioactive peptides [79]. Bioactive peptides have been defined as the specific molecule that positively impacts bodily functions or conditions and may, ultimately, influence overall human health [80]. Upon oral administration, bioactive peptides may affect the major body systems, namely, the cardiovascular, digestive, immune, and nervous systems [81]. Examples of biologically active food proteins and active peptides from various food protein sources, with physiological significance beyond the pure nutritional requirements that concern available nitrogen for normal growth and maintenance, have reported by Kitts and Weiler [82]. The active peptides have in common structural properties that include a relatively short peptide residue length (e.g., 2–9 amino acids), holding hydrophobic amino acid residues in addition to proline, lysine, or arginine groups. Plants produce a wide array of defense protein to control the attacks of microbial pathogens. As a result, several classes of proteins with antibacterial and/or antifungal properties have been isolated, identified, and recommended as antimicrobial agents [83]. Bioactive peptides are resistant to the action of both protease activity and digestion peptidases [82]. Antihypertensive peptides, known as Angiotensin I changing enzyme inhibitors, have been derived from milk, corn, and fish protein sources. Peptides with opioid activities are derived from wheat gluten or casein, following digestion with pepsin. Exorphins or opioid peptides derived from food proteins such as wheat and milk (e.g., exogenous sources) have a similar structure to endogenous opioid peptides, with a tyrosine residue located at the amino-terminal or bioactive site [82]. Immunomodulatory peptides derived from tryptic hydrolysates of rice and soybean proteins act to stimulate superoxide anions (reactive oxygen species – ROS), which triggers nonspecific immune defense systems [82].

In some cases, purified breast milk proteins, such as lactoferrin, lysozyme, a-lactalbumin, lactoperoxidase, milk fat globule membrane proteins, and β- and k-casein, may also provide bioactivities through a-lactalbumin, haptocorrin, and milk fat globule membrane [84]. Antimicrobial cationic peptides (AMPs) which constitute a heterogeneous class of low molecular weight proteins are important components of innate defense system directly interfering with the growth, multiplication, and spread of microbial organisms [85]. The action of AMPs targets mainly the bacterial cell membranes [86] due to their positive net charge enabling the binding and permeation of negatively charged phospholipid membranes of bacteria [87]. The frequent and massive use of antibiotics gave rise to multidrug-resistant bacteria [88]. Hence, the quest for new antibacterial agents is a continuous mission. A resistance to antimicrobial agents by pathogenic bacteria has emerged in recent years representing a major health problem [89], so the identification of new antimicrobial agents with different mechanisms of action is highly required. Cationic AMPs whose killing mechanism is due to the interaction with the cytoplasmic membrane are promising candidates [90]. Intensive research is currently devoted to understanding the effects of AMPs on intact cells using electron microscopy techniques to reveal the damage caused by these molecules on the bacterial morphology and membranes [91]. The role of AMP in combating pathogenic bacteria in food formulations with probiotic organisms is not clear.

From experimental data, the bioactive peptides were produced in vitro by gastrointestinal digestion of soybean seeds and soy milk. The analysis was performed on extracted protein samples from soybean seeds and milk or directly on untreated soy milk. The extracted protein samples from soybean seeds and soy milk were analyzed. The samples were subjected to simulated gastrointestinal digestion and then analyzed by nano-liquid chromatography coupled to tandem mass spectrometry for peptide sequencing. The identified peptides were 1,173 in soybean seed samples and 1,422 in soy milk samples. The peptide identifications were then employed to search specific databases and look for the presence of bioactive peptides with known biological activity or with potential antimicrobial activity. The soybean proteins underwent an extensive degradation process during gastrointestinal digestion and generated a large number of bioactive peptides, some with established activity, and some with predicted antimicrobial activity. In all probability, proteins or peptides found in soy milk samples could be formed during food processing [92, 93].

Carvalho et al. [94] reported that two cysteine-rich antimicrobial peptides (6.8 and 10 kDa) were isolated from different cultivars of cowpea (*Vigna unguiculata*) seeds and in three other leguminous seeds (*Vigna vexillata*, *Canavalia ensiformis*, and *Phaseolus vulgaris*). These active peptides showed the antifungal activety against *Fusarium oxysporum*, *Fusarium solani*, and the yeast *Saccharomyces cerevisiae*. Sequence analysis of these peptides showed the presence of a defensing and a lipid transfer protein (nsLTP) with a high degree of homology to other antifungal peptides isolated from plants [94]. Although native legume proteins were found devoid of antimicrobial activity, some of their components may be biologically active since they are a mixture of polypeptides with different biochemical properties. Some of these fractions may fulfill the requirements of the plant AMPs which represent the components of the innate defense system. Based on the positive net charges of some fractions, they can interact directly with the negatively charged bacterial membrane phospholipids increasing their permeation thus interfering with the growth, multiplication, and spread of microbial organisms [87]. The extensive use of antibiotics in different systems (i.e., humans, animal, or food) has resulted in the frequent emergence of resistant bacteria [95]. Also, the continued widespread use of chemical preservatives in food might poses a serious health problem reflecting high daily intake and the likely development of resistance through both spoilage and pathogenic bacteria. Thus, chemical preservatives could be replaced by bioactive natural molecules. The ingestion of bioactive molecules may have an effect on the major body systems, namely, the cardiovascular, digestive, immune, and nervous systems. According to their functional properties, bioactive molecule may be classified as antimicrobial, antithrombotic, antihypertensive, opioid, immune-modulatory, mineral binding, and anti-oxidative. There are many examples of biologically active food proteins [96], active peptides [97], phenolic plant extracts [98], and cold compressed oil [17] that can be obtained from various food protein sources and plants. They have a physiological significance beyond the pure nutritional requirements; in other words, they have the acquisition of nitrogen for normal growth and maintenance. Bioactive peptides are likely to contribute to the advantages of human nutrition and animal-farm feeding.

6 Bioactive Molecules from Herbs Extract and Fermentation

Another strategy is the use of tree leaves and local herbs extract – for raw milk and derived cheese bio-preservation. The traditional uses of tree leaves in cheese processing and packaging are already reported. Leaves and plants used by cheese makers today, though having long been a valuable aid for producers of small cheeses, now mostly have a purely decorative role, but some still use it in their traditional conservation purpose. Indeed, tree leaves might be used: (1) as a mould containing soft cheese (e.g., the "Jonchée Niortaise," molded in a rush mat; [99]), (2) to prevent the cheese from sticking one on each other during the ripening step in wooden trunks (e.g., "Feuille de Dreux" cheese; [100]), or (3) as moisture absorbers during ripening (e.g., "Mothais sur feuille", and formerly Langres and Chaource cheeses; [99]). Finally, leaves are also used for cheese packaging and/or ripening: vine or preferably chestnut leaves were one of the first packaging of cheeses. They first allowed keeping the products produced in excess, during heavy periods of lactation, for later consumption, weeks or months later. In France, the most picturesque of cheese preserved in tree leaves is manufactured in the scrubland of the Alpes de Haute-Provence and is known as "Banon cheese." This small goat milk cheese is prepared using soft curdling technique (this is due to a particularly hot climate in Banon county: milk had to be processed as quickly as possible in Ancient times), first ripened for 5–10 days before being wrapped in chestnuts leaves tied with raffia and ripened for at least 10 days at 12°C and 90% humidity. It will develop there the specific flavors of Banon thanks to anaerobic fermentation due to the tannin-rich rot-proof leaves. Thus wrapped, the cheese was safe from the air and kept safely until the dry period [99]. The Banon cheese is one of the few kinds of cheese to really use the virtues of these leaves.

The addition of natural extracts for cheese fortification (e.g., with the objective of improving consumer's antioxidant blood status) is presently more and more investigated under the angle of health products development [101, 102]. However, a few studies concerning the potent role of such extracts addition in bio-preservation processes are available. For example, protective effects of a green tea extract against oxidation induced by light exposure were suggested [103]. As a matter of facts, the afore-mentioned Jonchee Niortaise cheese is also sadly famous because the traditional use of cherry laurel (*Prunus lauro cerasus*) leaves for its flavoring led to numerous deaths due to cyanhydric acid acute toxicity [99].

7 Conclusions

From this survey of popular fermented dairy products in Egypt, it can be decided that the use of fermented milk as such, after conversion to cheese or dairy products, provides the human with essential amino acids, vitamins, and minerals. Use of Mish cheese as appetizers makes them an important part of the diet of most of the Egyptian population. Security and safety of these fermented foods in developing countries are recommended, as these foods are an essential source of protein and other essential nutrients for the human being.

8 Recommendations

So far, only a few studies have regarded traditional products fermented and ripened by exclusively natural microorganisms in order to respect local recipes and artisanal production processes. The safety of products like cheeses made from raw milk depends on the capacity of pro-technological starter/protective culture components to inhibit pathogenic microbes that can spread hazardous traits in the microbial community. Therefore, more efforts are needed to evaluate and implement the use of bacteriocinogenic bacteria or natural bioactive macromolecules such as peptides or extracts from the plant herbs in those products and their side effects on the pro-technological microbiota. The benefits could be a decreased risk for transmission of foodborne pathogens through the food chain, protection from spoilage and pathogen growth during temperature abuse, reduction of the economic losses due to food spoilage or contamination, and extended shelf-life.

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Part V
Potentiality of Soil Sensing for Sustainable Agriculture

Geostatistics and Proximal Soil Sensing for Sustainable Agriculture

Sameh M. Shaddad

Contents

Abstract Geostatistical tools coupled with proximal soil sensing data are of great importance for sustainable agriculture. They allow to have fine-scale information about key soil properties and consequently know where, when, and how much agricultural inputs should be added to soil to maximize the productivity, minimize costs, and reduce the environmental impact. Proximal soil sensors can be used for laboratory, in situ and on-line measurement conditions. This is fast, cost-effective, easy, and does not require expert operators to perform the analyses.

This chapter aims to provide an overview of the use of geostatistical techniques and proximal soil sensing data for achieving sustainable agriculture goals. Brief explanation of geostatistics and its applications as well as proximal soil sensors classifications were provided. A particular emphasis was given to the on-the-go

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platforms, especially a visible and near-infrared online platform. This chapter also shows several studies that were carried out by various researchers on the data fusion between proximal soil sensing data and geostatistical tools to detect the spatial and temporal variations of soil parameters. Once the soil variation was detected, variable rate technology can be applied.

Keywords Data fusion, Geostatistics, Proximal soil sensing, Sustainable agriculture

1 Introduction

Sustainability in agriculture aimed at minimizing agricultural costs, maximizing productivity, and reducing environmental impact. These aims can be achieved by knowing all available information about the soil-plant system through the use of proximal soil sensors and geostatistics that allow to have a fine-scale information about soil and plant properties. The obtained detailed information about soil and plant characteristics allow us to know where, when, and how much agricultural inputs should be added either to soil or to plant. Geostatistics is a wide-reaching field of spatial statistics, offering powerful tools for geospatial analysis. Most often it is used to interpolate estimates at locations where measurements have not or could not have been taken. As well as an interpolator, geostatistics provides a way of understanding spatial structure and can support the process of designing sample surveys. Potentially, proximal or ground-based (invasive or noninvasive) soil sensors have the ability to collect high-resolution data rapidly, and in certain cases even allowing real-time analysis and processing, by taking measurements as frequently as one per second [1]. Sensor-based soil analysis potentially provides several advantages over conventional laboratory methods such as lower cost, increased efficiency, more timely results, and collection of dense datasets while just traversing a field.

2 Geostatistics

Soil properties are continuous variables whose values at any location are expected to vary according to the direction and distance of separation from neighboring samples [2]. Therefore, the classic approach is inadequate for interpolation of spatially dependent variables, because it assumes random variation within units and no correlation between units and takes no account of relative location of samples. An alternative approach is to treat soil as a random function and to describe it using the methods of Matheron's regionalized variable theory (known as geostatistics) [3]. In this view there is no underlying mathematical relation between soil properties and their position on the ground. Even if there is, it is likely to remain unknown and in any case knowledge of it is unnecessary; relationships are instead expressed in terms of separation regardless of absolute position [4]. Geostatistics became quite well established in precision agriculture (PA) and the PA community had embraced geostatistics to explore the many kinds of data that farmers work with, mainly because the data are suitable for geostatistical analyses [5].

There are different definitions of geostatistics. According to Deutsch [6], geostatistics is the study of phenomena that vary in space and/or time. Geostatistics can be seen as a collection of different techniques that deal with spatial attributes characterization, utilizing primarily random models in a way similar to the way in which time series analysis characterizes temporal data [7]. Geostatistics describes spatial continuity of natural phenomena and uses classical regression techniques to take advantage of this continuity for predicting [8]. Geostatistics deals with spatially autocorrelated data.

Geostatistics is applied in many aspects of precision agriculture (PA) including sampling, prediction, mapping, decision making, variable-rate applications, economics, and so on. Contributions from experts in several fields of PA studies illustrate how geostatistics can be applied advantageously in the handling of data of different type, such as yield, soil, crops, pests, aerial photographs, remote and proximal imagery. Geostatistical techniques include variography, simple-, ordinary-, disjunctive-, indicator-, regression-, and space-time-kriging, factorial kriging and cokriging, and stochastic simulation [5].

To understand and process data geostatistically, the following fundamental elements should be well known:

1. Spatial dependency (or spatial autocorrelation)
2. Semivariograms (which are used to assess "spatial dependency")
3. The three components of spatial variation:
   (a) Structural or deterministic variation
   (b) Stochastic and spatially correlated variation
   (c) Spatially uncorrelated "noise" or random variation
4. Anisotropic variation (occurrence of directional spatial structures)
5. (Co)kriging and its various alternative approaches

2.1 Spatial Dependency

Spatial dependency describes the phenomenon where things that are close to one another are more likely to have similar values or properties than things that are further apart.

The theory of regionalized variables forms the basis of procedures for analysis and estimation of spatially dependent variables, known collectively as geostatistics. Geostatistics assumes that a spatial variation of any variable can be expressed as the sum of three major components. These are:

1. a deterministic component associated with a constant mean value or a long-range trend;
2. a spatially correlated random component;
3. a white noise or residual error term that is spatially uncorrelated.

A regionalized variable is a random variable varying in space. A regionalized variable $z(x)$ can be considered as a particular realization of a random variable $Z(x)$ for a fixed position x within the area. If all values of $Z(x)$ are considered at all locations within the area, $Z(x)$ becomes a member of an infinite set of random variables, called a random function $Z(x)$. All the random variables have the same probability distribution function $F(z)$, independent of x.

2.2 Semivariogram

The semivariogram is the pillar of geostatistics and is a way to assess spatial correlation in observations measured at sample locations. It is commonly represented as a graph that shows the semi-variance of all observation pairs sampled at a distance. Such a graph is helpful for building a mathematical model that describes the variability of the observations as a function of separation distance. Modeling of such a relationship is called semivariogram modeling. It is used in applications involving estimating the value of a property at a new location. Semivariogram modeling is also referred to as variogram modeling.

There are three important features of an upper bounded semivariogram (Fig. 1):

Range: describes the spatial limits of spatial dependency, or the distance beyond which points are spatially uncorrelated. If the distance between two adjacent observations exceeds this distance, then traditional (regressive) techniques of interpolation can be used.

Sill: describes the part of the variogram where it levels off at a distance equal to or greater than range.

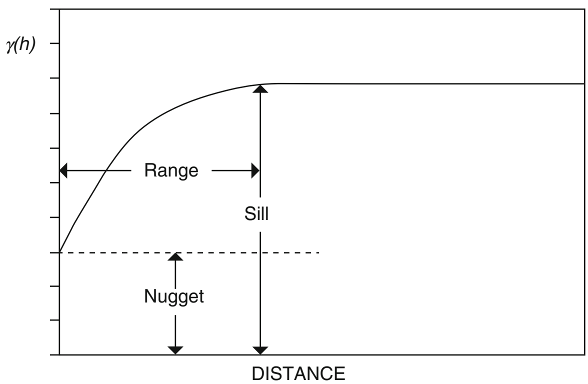

Fig. 1 Theoretical semivariogram [4]

Nugget: represents the spatially uncorrelated noise (including the variance of measurement error and micro-variation at a scale smaller than sampling scale).

3 Methods of Interpolation

3.1 Kriging

Kriging is a type of interpolation technique. The procedure is similar to averaging techniques of interpolation but the weights are derived from the spatial arrangement as well as from the distance between nearby points, i.e., from the variogram. The fitted variogram or the directional variograms (for anisotropic variation) is/are used to determine the weights λ_i needed for local interpolation.

The weights are chosen so that the estimate is unbiased, and that the estimation variance is less than for any other linear combination of the observed values.

Mapping the spatial distribution of a soil property involves interpolation or spatial prediction. Geostatistical interpolation uses the variogram to optimize prediction by kriging. The most basic form of kriging is ordinary punctual kriging in which the unknown value $z(x_0)$ of a given realization of $Z(x_0)$ in an unsampled point x_0 is predicted from the known values $z(x_i)$ $i = 1, 2, \ldots, N$, at the support points x_i of the same realization using a so-called "best linear unbiased estimator" (BLUE). The best linear unbiased predictor $z^*(x_0)$ of $Z(x_0)$ is given by a linear combination of the observations:

$$z^*(x_0) = \sum_{i=1}^{N} \lambda_i z(x_i)$$

where λ_i are weights. The weights are chosen in such a way that the estimator is unbiased:

$$E[Z^*(x_0) - Z(x_0)] = 0$$

and the estimation is minimized.

Using a Lagrangian multiplier μ, minimization of the estimation variance under the constraint of unbiasedness yields a set of $N + 1$ linear equations:

$$\begin{cases} \sum_{j=1}^{N} \lambda_i \gamma\left(x_i, x_j\right) + \mu = \gamma(x_i, x_0) \quad i = 1, \ldots, N \\ \sum_{j=1}^{N} \lambda_j = 1 \end{cases}$$

from which the λ_j and μ can be calculated. The estimation variance is then given by:

$$\sigma^2(x_0) = \mu + \sum_{i=1}^{N} \lambda_i \gamma(x_i, x_0)$$

Alternatively, equivalently:

$$\sigma^2(x_0) = 2\sum_{i=1}^{N} \lambda_i \gamma(x_i - x_0) - \sum_{i=1}^{N} \sum_{j=1}^{N} \lambda_i \lambda_j \gamma(x_i - x_j)$$

and represents the uncertainty in the prediction in x_0: $\gamma(x_i, x_j)$ and $\gamma(x_i, x_0)$ are the semi-variances between the observed locations x_i and x_j and between the observed location x_i and the interpolated location x_0, respectively. In the case of spatial dependence, semi-variance tends to increase with the distance between observations; therefore errors decrease with the density of data and not just with their total number, as is the case with traditional statistical models. It needs to be pointed out that kriging is optimal and unbiased only on the condition that the model is correct. However, predictions are only slightly affected by the choice of the model, provided it is reasonable of course. This is one of the strengths of kriging that is robust enough in this sense; however, error variances can be seriously affected by the model.

Kriging has many useful properties [4]:

- The interpolated value is the most precise in terms of mean squared error
- The interpolated value can be used with a degree of confidence, because an error term is calculated together with the estimation
- The estimation variance depends only on the semivariogram model and on the configuration of the data locations in relation to the interpolated point and not on the observed values themselves
- The conditions of unbiasedness ensure that kriging is an exact interpolator, because the estimated values are identical to the observed values when a kriged location coincides with a sample location. In this case the weights within the neighborhood are all zero and the estimation variance equals the observation.
- Only the nearest few samples are spatially correlated to the kriged location and therefore they are the most weighted. Two important advantages become clear: first, the variogram needs to be accurate only in the first few lags; second, whatever is gained from introducing distant points is limited also because sample locations interposed between the kriged point and more distant samples screen the distant ones by reducing their weights.

4 Geostatistics and Precision Agriculture

The principle of precision agriculture (PA) has an even longer history than geostatistics. It has been carried out by farmers since the early days of agriculture. "They divided their landholdings into smaller areas, fields, to grow crops where the conditions were most suitable" [5].

Modern PA appears to have its origins in the mid-1970s to early 1980s; farmers were becoming more aware of the potential benefits of better farm record keeping and understanding of soil and crop input requirements [9]. There was a better awareness of within-field variation in the properties of soil and crop, and of the potential benefits of within-field management by zones. Associated with this there was a mushrooming of technology and services in response to the needs of this approach to agriculture, e.g., yield monitors and variable-rate spreaders. The concept of modern precision agriculture has also been driven forward and is underpinned by technological changes based on information technology [10].

Precision agriculture term was first emerged in 1990 as the title of a workshop held in Great Falls, Montana, sponsored by Montana State University [5]. The focus was on more precise local management, i.e., site-specific management (SSM), and consequently the unit of management became the field and its intrinsic variation was of interest. This shows a change in the operation scale from macro to micro scale (within-field), but there is more to it than this. In the developed countries and with the increase in machinery size that is used in agriculture, farmers merged fields into increasingly larger areas. So variations of the original fields were added together. Therefore, the within-field variability increases as the field size increases [5].

Before the 1990s, maps, other than of the soil and possibly landscape, played little part in agricultural management. Schafer et al. [11] said at this time that maps of soil type and topography could be used to control fertilizer and pesticide applications and tillage operations. A major stumbling block to the wider spread and adoption of PA is the sparsity of soil and crop information, although there have been examples of on-the-go measurement of pH [12]. The National Research Council [13] also made the point that "current mapping techniques are limited by a lack of understanding of geostatistics necessary for displaying spatial variability of crops and soils," and "An increased knowledge base in geostatistical methods should improve interpretation of precision agriculture data."

From the quotations given above, it can be concluded that the geostatistics is essential in PA. In fact, the early applications came from scientists already familiar with geostatistical methods. PA provides a lot of data that suffices the needs in calculating reliable variogram [5].

5 Site-Specific Management Zones

Geostatistical techniques have been adopted with some enthusiasm in PA because they allow to quantify and predict the spatial variation of soil, crop, and landscape properties [5]. Natural systems in the environment usually show structured or periodic variation in time or space (i.e., spatial or temporal dependence). This is particularly true for soil systems where patterns develop as a result of variation in topography, parent material, climate, and biology. The consequence of spatial dependence is that samples separated by small distances tend to be more similar than those separated by large distances. On the other hand, classical statistical procedures assume that data are spatially independent. In the geosciences, geostatistics have been used for some time [5]. In geostatistical analysis, there are two major steps: modeling spatial dependence by creating a correlogram or variogram, and predicting variable values at unsampled locations with different techniques such as kriging or cokriging. Geostatistics can provide accurate maps for the successful application of variable-rate fertilization and other applications in precision agriculture, such as irrigation [5]. To quantify the spatial variation in a given field, sample design used to obtain data is important. Geostatistics places a different emphasis on the approach to sampling from that used in conventional statistics.

6 Delineation of Site-Specific Management Zones

The delineation of management zones (MZ) is a cost-effective tool for site-specific applications of inputs. The traditional methods to delineate management zones don't consider the spatial relationships between the observations. Geostatistics treats multivariate indices of spatial variation as continua in a joint attribute-geographical space.

Castrignanò et al. [14] reported that in geostatistics sparse observations of the primary attribute can be complemented by secondary attributes that are more densely sampled and this is an advantage of geostatistics over simpler spatialization methods. Two methods were applied to incorporate dense secondary information. The first one was multicollocated cokriging, which restricts the neighborhood to the only secondary data, collocated with the target location and with the available data of the primary variable. The second was simple cokriging with varying local means related to crisp classes. Their objective was to find the method that best improves the estimation of primary attributes through dense secondary information for an area of about 3,820 km^2 located in province of Siena in central Italy. After the two methods were compared in terms of precision, through cross-validation, and accuracy, through a validation test, using an independent data set of 170 soil depth measurements. There were no clear differences among the methods from obtained results.

Castrignanò et al. [15] proposed a quantitative approach to unambiguously locate, characterize, and visualize agro-ecozones and their boundaries which can be associated with different environmental conditions. They used environmental parameters, including climatic and soil characteristics, hypothesized to be generally relevant to many crops in Capitanata-Foggia (South Italy). A clustering algorithm based on nonparametric multivariate density estimation was applied to cokriged environmental estimates at 500 m scale. The study area was delineated into five compact classes in the space of environmental attributes that were also contiguous in geographic space. The resulting agro-ecozones can help land use decision makers.

De Benedetto et al. [16] stated that proximal sensors such as electromagnetic induction (EMI), ground penetrating radar (GPR), hyperspectral spectroscopy (HS), and remote sensing (RS) can be used as complementary data with direct sampling.

However, sensor data fusion approaches still in need of developing. The objective of their work was to define a multivariate and multi-sensor approach by amalgamating EMI, GPR, RS, and HS data, without any previous weighing, in order to delineate an 1.5 ha arable field into homogenous zones. The multi-sensor data were divided into four groups: the first and second groups consisted of bulk electrical conductivity (EC) from EMI data and amplitude of GPR signal data respectively. The third group included the first principal components relating to five bands [green, yellow, red, red edge, near-infrared (NIR) PCs] of hyperspectral reflectance data. The last group consisted of the vegetation indices (NDVI, NDRE and NIR/Green) calculated from the remote sensing images. Interpolation by cokriging or kriging was applied to the data of each group at the nodes of the same grid. For obtaining spatially contiguous clusters, a combined approach of multivariate geostatistics and a nonparametric density function algorithm of clustering was applied to the overall multi-sensor data set of the estimates. Three homogenous zones were delineated through the full approach. These are cluster 1, in the NW part of the field characterized by the lowest values of bulk electrical conductivity and GPR amplitude, and the highest red PC values. The other two clusters were delineated in the SE part of the field, with the highest values of green, yellow, red edge, and NIR PCs for cluster 2, and the highest values of bulk electrical conductivity and vegetation indices for cluster 3. The delineated homogenous zones can be used to develop a prescription map for site-specific management.

Aggelopooulou et al. [17] studied several factors for the MZ delineation including crop and soil characteristics. They applied multivariate analysis to delineate MZs in an apple orchard in Greece. Soil and crop data were collected during 3 years from a Precision Agriculture project. The collected data were categorized into three groups, namely soil properties, yield, and fruit quality. All data were analyzed for descriptive statistics and their distribution. Spatial variability maps of the 3 years were presented. Data were jointly analyzed for management zone delineation using a combination of multivariate geostatistics with a nonparametric clustering approach, and the orchard was divided into four zones which could be differently managed. However, more research and experimentation are needed before adopting precision horticulture in Greece.

Diacono et al. [18] proposed a combined approach of multivariate geostatistics and nonparametric clustering for delineation of homogeneous zones that could be potentially managed with the same manner. In a durum wheat field of Southern Italy, in organic farming, different soil physical and chemical properties (electrical conductivity; pH; exchangeable bases; total nitrogen; total organic carbon; available phosphorous), elevation and the Normalized Difference Vegetation Index were determined and interpolated using geostatistics. The clustering approach, applied to the (co)kriged estimates of the variables, produced the delineation into four subfield zones. There was no significant relation between soil fertility and yield in such zones. However, the proposed approach has the potential to be implemented in future applications of precision agriculture.

7 Proximal Soil Sensing

In precision agriculture, the use of proximal soil sensors is highly recommended, as these can provide high-resolution data on spatial variation in soil properties [19], which enables the management of land at field and subfield scale.

Viscarra Rossel et al. [20] classified proximal soil sensors based on different aspects as illustrated in Fig. 2.

Another classification suggested by Kuang et al. [21] for laboratory, in situ non-mobile, and on-line mobile measurement conditions is:

- Conductivity, resistivity, and permittivity based soil sensors
- Passive radiometric based soil sensors
- Strength based soil sensors
- Electrochemical based soil sensors
- Reflectance based soil sensors

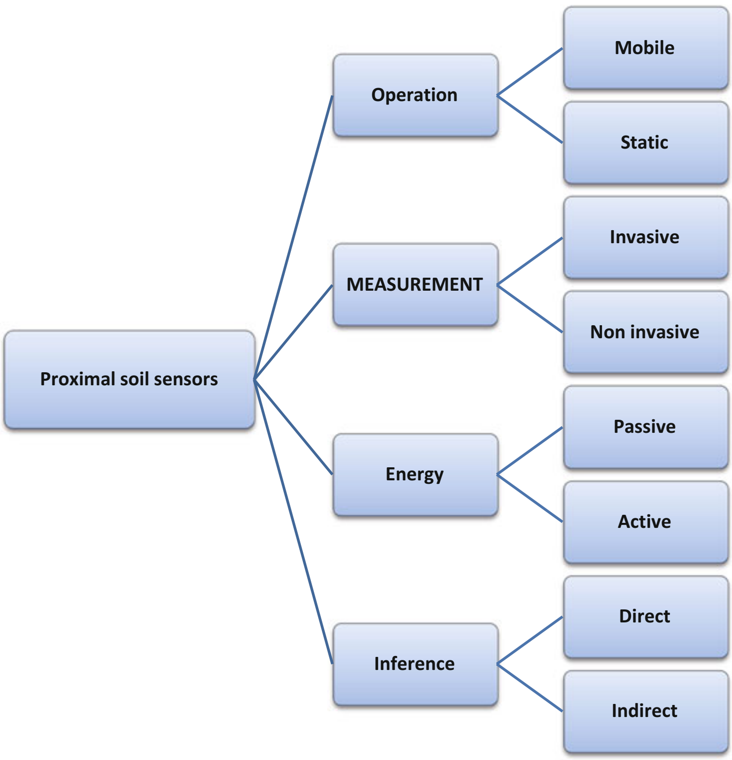

Fig. 2 Proximal soil sensors classification

7.1 Mobile (On-line) Field vis-NIR Sensors

So far there are only three on-line vis-NIR systems in the world. They are of Christy [22], Mouazen et al. [23], and Shibusawa et al. [24].

The on-line vis-NIR sensor (Fig. 3) designed and developed by Mouazen [25] consisted of a subsoiler that penetrates the soil to the required depth, making a trench, whose bottom is smoothened due to the downwards forces acting on the subsoiler [23]. The optical probe was mounted to the back side of the subsoiler chisel to record soil spectral reflection from the smooth bottom of the trench. The subsoiler, retrofitted with the optical unit, was attached to a frame that was mounted onto the three-point linkage of the tractor [23]. An AgroSpec mobile, fiber type, vis-NIR spectrophotometer (tec5 Technology for Spectroscopy, Germany) with a measurement range of 305–2,200 nm was used. The spectrophotometer was IP66 (ingress protection) protected for harsh working environments. A 20 W halogen lamp was used as a light source. A differential global positioning system (DGPS) (EZ-Guide 250, Trimble, USA) was used to record the position of the on-line measured spectra with sub-meter accuracy. Data logging and communication were achieved by a Panasonic semi-rugged laptop. The power of the spectrometer system, laptop, and DGPS was provided by the tractor battery. A New Holland T5000 tractor with 100 Ah battery was used. The total power consumption for all electrical parts of the on-line vis-NIR sensor was around 60 W.

Fig. 3 The on-line visible and near infrared (vis-NIR) soil sensor [25]

8 Data Fusion

According to Durrant-Whyte [26] data fusion is a kind of amalgamation of different sources of information to provide a robust and complete description of an environment or process of interest. Data fusion is of great importance in any application where large amounts of data must be combined, fused, and distilled to obtain information of appropriate quality and integrity on which decisions can be made. Data fusion can be used in different fields such as military systems, civilian surveillance, and monitoring tasks, process control, and information systems. Data fusion techniques are particularly important in achieving autonomous systems in all these applications. In principle, automated data fusion processes allow to complement essential measurements and information to formulate and execute decisions autonomously.

Definitely, having an additional data set must help, particularly if it is measuring the same thing. If not, it will still help if the second measurement is correlated with the first.

Piikki et al. [27] predicted the topsoil clay content in a field of 22 ha in southwest Sweden through data fusion of proximal sensors. They used eight different predictor sets that were different combinations of proximally measured gamma (γ)-ray spectrometry and apparent electrical conductivity (ECa), four terrain attributes (elevation, slope, and the cosine and the sine of aspect) and the digital numbers (DNs) of an aerial photo. Two different calibration methods were used. Those were partial least squares regression (PLS-R) and k nearest neighbor prediction (kNN). Results showed that γ-ray spectrometry variables (232Th, 40K, and total count of decays) were good predictors of topsoil clay content with mean absolute error of about 1.5% clay and predictions were neither much improved nor deteriorated by addition of any of the other predictors. The ECa measurements performed poorly. Integration of ECa data with the aerial photo DN improved predictions whereas adding elevation data deteriorated predictions. The kNN method performed slightly better than the PLS-R method in predictions. It was found that the use of proximal soil sensor data gave better results than mere interpolation of the calibration samples. Sparse circumstances identify several unequivocally problematic.

Geo-electrical sensors are often used as secondary variables with sparse direct measurements to predict soil parameters. Using a single sensor is not enough in some circumstances. For example, sandy, sandy gravelly, sandy salt-affected, and clayey soils are poorly identified using an EMI or gamma-ray sensor singularly. Integration between sensors should improve interpretation in landscapes containing these soils. Analysis of multi-sensor data is however challenging. Different methods have been developed to integrate multi-sensor data but currently there is no accepted methodology [28].

Castrignanò et al. [28] used EMI, gamma-ray emission, and GPS height as multi-sensor auxiliary data for soil characterization. Their objectives were as follows: (1) To identify a data fusion approach between soil samples and sensor data by geostatistics. The fused data consisted of electromagnetic induction (EMI) measured with EM38 and EM31, gamma (γ)-ray and RTK GPS sensors and soil sample data to delineate areas of homogeneous soil. (2) To show the potential of gamma radiometric sensor in predicting crop available soil potassium (K) from the γ-ray signal. The geophysical survey was conducted in an 80 ha cropping field in Corrigin, Western Australia. A total of 77 soil samples were collected based on at the 100 × 100 m-mesh grid and analyzed for different properties. The multi-sensor data were divided into four subgroups, according to their similarities: (1) EMI data; (2) γ-radiometric counts from potassium (emitted from all forms of K including readily plant available, non-exchangeable, and structural K); (3) γ-radiometric counts from Th, U, and TC, and (4) RTK GPS height. Multi-collocated cokriging was successfully implemented on soil samples and geophysical data for interpolation. An anisotropy was observed in the EMI data and an anisotropic Linear Model of Coregionalization was fitted before cokriging. Both EM31 and EM38 maps looked quite similar. Also, maps of γ-U, Th, and TC were similar, indicating that they reflected the same soil properties, but were somewhat different from the γ-K maps. High values of EMI coincided with low γ-radiometric values at the valley bottom may be attributed to moist sandy salinity-prone soil of varying depth to texture contrast. Whereas with high γ-radiometric values at the elevated areas of the field, it may be ascribed to emission from finer textured soil. High γ-radiometric values coincided also with low values of EMI over gravelly sands. Only the use of a multi-sensor platform could differentiate soils having similar outputs to one sensor. To delineate the field into homogeneous zones, the first two principal components of the geophysical data were used.

9 Brief Description of Data Fusion Case Study

An example of data fusion between visible and near infrared spectral data and laboratory analysis data is a research achieved by Shaddad et al. [29]. In this research, eight laboratory measured soil variables (pH, P, CEC, TN, TC, K, sand, and silt) and four vis-NIR predicted soil variables (pH, P, K, and moisture content) were used. The two types of variables were collected together in one multivariate coregionalization dataset to delineate the management zones. From the multivariate coregionalization dataset, a linear model of coregionalization was created and finally multi-collocated factor cokriging was successfully applied to display the management zones. Multi-collocated factor cokriging analysis resulted in two factors, factor 1 (F1) (Fig. 4) which explained that about 46% of the spatially structured component of variance was mainly and positively correlated with soil TC, pH, TN, and at a less extent CEC. Since these variables are expected to affect soil fertility greatly, F1 was interpreted as a soil fertility indicator. Factor 2 (F2) (Fig. 5), explaining about 20% of the corresponding scale-dependent variance, was negatively correlated with silt and positively correlated with sand; hence it can be interpreted as a soil texture indicator.

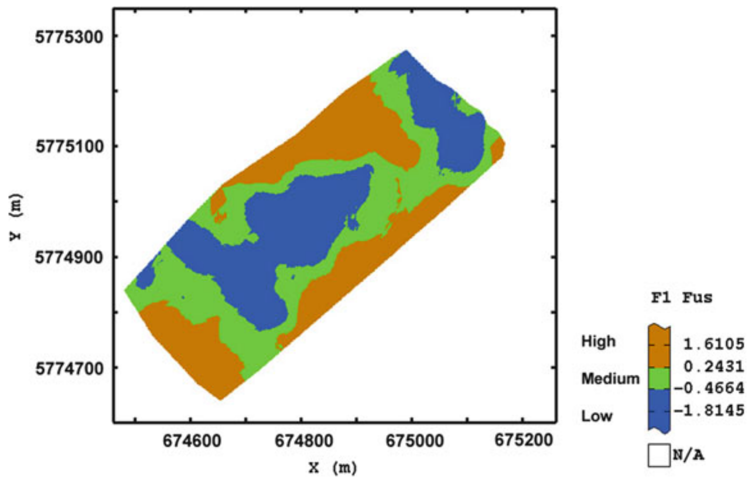

Fig. 4 Delineated management zones according to the scores of the F1

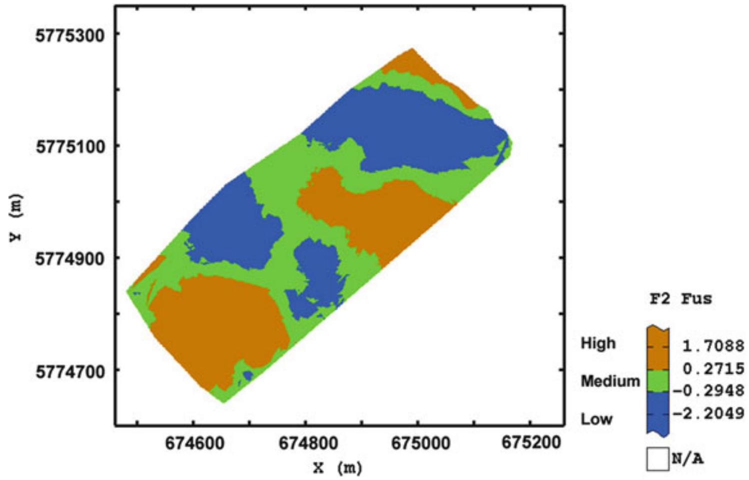

Fig. 5 Delineated management zones according to the scores of the F2

To assess the productivity potential of the different zones of field, spatial association between MZs of F1and barley yield map classes was calculated after grouping the yield map into three iso-frequency classes. The overall association between the two maps was calculated to be equal to 38.6%, which indicates that the management zone delineation produced by F1 can explain only about 40% of the total yield variability, whereas more than 60% is ascribable to more dynamic factors not treated in this study. These dynamic factors might include agro-meteorological conditions, plant diseases, and nutrition stresses, which may affect the final crop production noticeably. Monitoring of the latter factors might aid to detect on-time the likely causes of variation in yield.

10 Applicability in Egypt

In Egypt, proximal soil sensing and geostatistics tools can be applied for the purpose of sustainable agriculture. This will result in delineating management zones and then apply the variable rate technology (VRT). VRT application will maximize productivity, minimize agricultural costs by reducing the exaggerating applications of agrochemicals, and reduce the environmental impact. Generally, this will allow to have safe food and consequently enhance the population health.

There are some unpublished results of the author about the application of geostatistical tools and proximal soil sensing in delineating management zones in Egypt for the purpose of soil reclamation and variable rate fertilization.

11 Conclusions

The marriage between proximal soil sensing and geostatistical techniques is important to assess spatial variability of soil properties not only over large scales but also at micro scales (within-field). Visible and near infrared spectroscopy is considered as one of the proximal soil sensing methods, which may provide detailed information about soil parameters. It is also easy to use, relatively cheap, fast, and does not require expert operators to perform the analysis. Geostatistical tools are important as they allow to assess more accurately spatial variation of soil properties.

12 Recommendation

To achieve sustainable agriculture, it is necessary to know all information about the soil-plant system. This cannot be achieved by the traditional methods based on averages of laboratory measured data. So it is recommended to use the developed tools such as proximal soils sensors that allow to have fine-scale information about soil and plant parameters easily. The proximal soil sensing data can be complemented with laboratory measured data through geostatistics to better recognize soil spatial variability. Geostatistics allows to predict soil properties in unsampled locations and consequently to delineate site-specific management zones which are used for variable rate applications.

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Sustainable Indicators in Arid Region: Case Study – Egypt

Elsayed Said Mohamed, Mohamed Abu-Hashim, and Abdel-Aziz A. Belal

Contents

Abstract Increasing of population and scarcity of water resources in arid and semiarid countries are one of the major obstacles to sustain agricultural development. When we are talking about Egypt as a case study, there are many reasons that impede sustainable development. These reasons could vary according to spatial distribution. That the urban sprawl is considered one of the most serious factor that impedes the sustainable development in the Nile valley and delta. On the other hand, the northern regions of the Nile Delta face another critical situation that affects the agricultural development and maintaining its development. The northern part suffers from land degradation due to high salinity levels besides rising of the groundwater table. Therefore, this chapter focuses on the assessment of sustainable agricultural development according to several axes. It discusses land productivity, security, protection, validity, and acceptability as well as economic and social factors. Remote sensing techniques and GIS as new trends have been reviewed

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and considered in this chapter to assess and mapping sustainability degree. Three different methods were reviewed throughout this chapter, and these methods depend on integrating environment, economy, and society factors.

Keywords Remote sensing, Spatial distribution, Urban sprawl, Water scarcity

1 Introduction

Sustainable development is defined as "development that meets the needs of the present without compromising the ability of the future generations to meet their own needs" [1]. Egyptian territory area about 1 million km^2 is made up as follows: Nile valley and delta about 4% of the total; Eastern desert area about 22%; Western desert area about 68%; and Sinai Peninsula area about 6%. The share of Nile water in Egypt is 55.5 billion m^3 year^{-1}, representing 76.7% of the country's available water resources; desalinated seawater comprises only 0.08%. Total groundwater plus treated groundwater is 20.65 billion m^3 year^{-1} (28% of available water resources), but it cannot be added to Egypt's share of water as it is a reused source [2]. Sustainable agriculture is increasingly viewed as a long-term goal that seeks to overcome problems and constraints that confront the economic viability, environmental soundness, and social acceptance of agricultural production system both in the USA and worldwide. While there are many definitions of sustainable agriculture, most of them espouse the same elements of productivity, profitability, conservation, health, safety, and the environment, that differ only in the degree of emphasis. There is a general agreement that sustainable development includes environmental, economic, and social dimensions [3]. Sustainability indicators characterizing these three dimensions are generally used to bridge the gaps between theoretical concepts and actual measures [4, 5].

Sustainable agriculture is farming systems that are maintaining their productivity and benefit to society indefinitely [6]. Despite the diversity in conceptualizing sustainable agriculture, there is a consensus on three basic features of sustainable agriculture: (1) maintenance of environmental quality, (2) stable plant and animal productivity, and (3) social acceptability. A sustainable farming system is productive and safe and conserves the natural resource base. Moreover, there are several problems faced by sustainable development such as loss of soil productivity from excessive erosion/intensive cultivation and associated plant nutrient loss/depletion; surface and groundwater pollution from pesticides, fertilizers, and sediments; impending shortages of nonrenewable resources; and low farm income due to low commodity prices and high production costs [7]. Sustainable Land Management (SLM) in agriculture is a very complex and challenging concept that encompasses biophysical, socioeconomic, and environmental concerns that must be viewed in an integrated manner. An international Framework for Evaluating Sustainable Land Management (FESLM) was developed to provide a base for addressing these issues comprehensively. SLM combines technologies, policies, and activities aimed at integrating socioeconomic principles with environmental concerns so as to simultaneously satisfy the five pillars of SLM. Those pillars are as follows: to protect the potential of natural resources and prevent degradation of soil and water quality (protection), to reduce the level of production risk (security), to be economically viable (viability), to maintain the production services (productivity), and to be acceptable (acceptability). The information and data obtained from the studied area have been analyzed according to the FELSM methodology to develop SLM indicators that address the five pillars of the FESLM. Knowledge from the farmers themselves through 58 questionnaires held with them in suite and many publications concerning the investigated area have been acquainted.

2 Obstacles to Sustainable Development

Sustainable development in arid and semiarid regions faces many constraints. These constraints vary according to geographical location, socioeconomic conditions, and climate. This section will review the main obstacles as follows:

- High population growth and pressure; agriculture production has to be increased by 70% within 2050 in order to face the population growth and changing diets [8]. Agriculture will furthermore need to minimize the emissions of greenhouse gases, pesticides, and plant nutrients like nitrogen and phosphorous to the environment. However, this production increase will have to be achieved in a way that preserves the environment and reduces the vulnerability of agriculture to climate change.
- Dependency of livelihoods on agriculture; with 65–70% of the population depending directly on rain-fed agriculture and natural resources. Industry and the service sector also depend heavily on land management [9].
- Climate change: these include higher temperatures, water scarcity, unpredictable precipitation, higher rainfall intensities, and environmental stresses [10]. Since the industrial revolution has already deeply impacted ecosystems, the main concept from the climate change story is that public do not recognize and trust scientists until it really hurts. In addition, all society issues cannot be prepared using the old and painkiller approaches because all issues are now huge, linked, global, and fast-developing. Thus, actual society structures are probably outdated. Here, agronomists are the most advanced scientists to solve social issues because they master the study of complex systems, from the molecule to the global scale. Now, more than ever, agriculture is a central point to which all social issues are bound; indeed, humans eat food [6].
- Land degradation has negatively affected the state and the management of the natural resources (soil, water, and plants). Land degradation occurs in different forms on various land-use types:

For cropland: soil erosion by water and wind forces; water degradation mainly caused by increased surface runoff (polluting surface water) and changing water availability as well as high evaporation leading to aridification, chemical degradation – mainly fertility decline – due to nutrient mining, and salinization; soil physical degradation due to crusting, sealing, and compaction. That leads to insufficient vegetation cover, decline of local crop varieties, and mixed cropping systems.

For grazing land: biological degradation with loss of vegetation cover and valuable species; the increase of alien and "undesirable" species. The consequences in terms of soil physical degradation, water runoff, and erosion are widespread and severe. Low productivity and ecosystem services from degraded grazing lands are widespread and a major challenge to SLM http://www.fao.org/docrep/014/i1861e/i1861e01.pdf.

3 History of Sustainability

Sustainable development is a major concern of all nations given the need to preserve the global environment. Since the Stockholm Declaration, signed in 1972, there have been many initiatives towards global environment protection [11]. In Den Haag, some 24 leading countries have signed a declaration to harness global climate change. Moreover, in June 1992 the United Nation World Summit in Rio de Janeiro produced piles of documents pledging to sustain the global environment [12]. Also, many governments including the federal and provincial governments in Canada as well as the Consultative Group on International Agricultural Research (CGIAR) have indicated that SLM is a matter of priority in the coming years. Some international agencies in cooperation with national research institutions in Canada, the USA, and others have collaborated to develop the principles and recommended procedures for a Framework for Evaluating Sustainable Land Management (FESLM), and to host two international workshops. The first was in Chiang Rai, Thailand, in 1991, which resulted in the formation of an International Working Group (IWG) to further the development of the FESLM, and the second was in Lethbridge, Canada, in 1993, which focused on the indicators to be used for evaluation of sustainability. Results from this work were reported at a symposium at Acapulco, Mexico, as part of the 15th World Congress of Soil Science. Recently in 1997, the Second World Summit was held in New York to evaluate the implementation of all commitments and of the agenda formulated in Rio de Janeiro and to draw up an action plan to sustain our planet for the next century, and the more distant future [13].

4 Methods Used to Assess Sustainable Land Management

Several methods and indicators have been proposed to assess sustainability condition during last three decades, and in this section we review three frameworks:

1. Liu and Zhang [14] proposed a methodological framework for assessing the sustainability level of main agricultural regions in China on regional and county levels. Four sustainable categories were distinguished: environmental, social, economic, and comprehensive sustainability. The two distinguished methods for measuring the sustainability were:

   (a) The balanced performance method that measures balanced performance among different aspects of sustainability; a minimum value method was used according to the following equation:

   $$\mathrm{CI}_c = \operatorname*{Min}_{j=1}^{n} \; v_j\left(x_j\right)$$

   and

   (b) The aggregate achievement method that measures aggregate achievement of all aspects. This method aims at aggregated using multi-attribute value theory, a compensatory method, because of its ability to analyze many dimensional conditions and allow the conduction of assessments [15]. The value function of the additive model was used because of its simplicity.

   $$\mathrm{CI}_c = \sum_{j=1}^{n} w_j v_j\left(x_j\right)$$

   where CI_c is the comprehensive sustainability of county c, w_j is the weight of the sustainability indicator j estimated by Analytic Hierarchy Process (AHP) that was employed to determine factor weight, n is the number of indicators, and v_j (x_j) transforms individual indicator x_j into commensurable units between 0 and 1.

   Spatial variation maps of sustainability across countries were produced using a geographic information system (GIS) for generating, displaying, and spatially analyzing information for the measurement of sustainability. Moreover, the author classified the degree of sustainability into five ratings (very low, low, medium, high, and very high). The limiting factors in each region were identified. The same author identified 14 indicators suitable for assessing sustainability framework at the county level. For each indicator, concise definitions, methods of calculation, and indicator type were shown in Table 1.

2. Cornelissen [16] proposed a novel approach to quantify agricultural sustainability using fuzzy set theory. This approach aims at interpreted as to what extent agricultural production systems are able to meet the joint demands, where it considered the joint economic, ecological, and societal perspectives on

Table 1 A novel approach to quantify agricultural sustainability

Dimension	Implication	Indicator	Indicator definition	Indicator type	Weight
Environmental	Land quality index	Shares of top quality land in total	Shares of first- and second-grade land in total land (%)	Positive	0.23
Sustainability		Land limitation level	Shares of above third-grade limited land in total land (%)	Negative	0.25
	Resource carrying index	Cropland per capita	Cropland per capita (ha per person)	Positive	0.15
		Water resource stress index	$C = K X \sqrt{(P X / W)}$ $K = \begin{cases} 1.0 & R \leq 200 \\ 1.0 - \frac{0.1 \times (R - 200)}{200} & 200 < R \leq 400 \\ 0.9 - \frac{0.2 \times (R - 400)}{400} & 400 < R \leq 800 \\ 0.7 - \frac{0.2 \times (R - 800)}{800} & 800 < R \leq 1600 \\ 0.5 & R > 1600 \end{cases}$ where p indicates the population ($\times 10^4$ person) A indicates the irrigation area ($\times 10^3$ ha) W represents the total water resources ($\times 10^8$ m^3) K is the coefficient related to rainfall, and R is rainfall (mm)		
	Ecological risk index	Land degradation level	Shares of degraded land due to erosion, salinization, and desertification in total land (%)	Negative	0.12
		Pesticide usage	Pesticide consumption per hectare of cropland (km per ha)	Negative	0.07
Economic	Intensity of land management	Chemical fertilizer consumption	Chemical fertilizer consumption per hectare of cropland (km per ha)	Double meaning	0.25
Sustainability		Effective irrigation rate	Shares of irrigated land in total cropland (%)	Positive	0.31
		Degree of agricultural machinery inputs	Total horsepower of agricultural machinery per hectare of cropland (kw per ha)	Positive	0.19
		Financial investments in agriculture	Agricultural financial investments per hectare of cropland (per person)	Positive	0.13

	Economic benefit	Gross output value of farming	Gross output value of farming per hectare of cropland per person	Positive	0.12
Social	Social prosperity	Gross Domestic Product (GDP) per capita	Gross Domestic Product (GDP) per capita	Positive	0.33
Sustainability	Food security	Grain yield per capita	Grain yield per capita (kilograms per person)	Positive	0.41
	Social instability	Income gap between urban and rural population	Per capita annual disposable income of urban households/per capita annual net income of rural households	Negative	0.26
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agricultural production systems. Since agricultural sustainability is approximated by a selection of sustainability variables, the acceptability of achievements should be determined for every selected sustainability variable. Such a degree of acceptability can be determined using fuzzy set theory [17, 18]. Agricultural sustainability should, therefore, not aim at designing agricultural production systems that last forever in a definite form but monitor the continuous process of adapting agricultural production systems to the specific economic, ecological, and societal systems they are embedded in. Considering the necessary selection of a limited number of sustainability variables, and as a result of the mutually emerging trade-offs, it is impossible to determine indisputably whether an agricultural production system is sustainable or unsustainable. Applying conventional, two-valued logic (e.g., sustainable-or-unsustainable type decisions), therefore, comes to an unsatisfactory conclusion [19–21]. Fuzziness describes event ambiguity: it measures the degree to which an event occurs [22]. Fuzziness, therefore, relates to multivalued logic [19], e.g., all intermediate situations between sustainable and unsustainable are possible. This means that agricultural production systems can be assessed as partially sustainable.

3. This method depends on three steps: sustainability variables, membership functions, and combining degrees of acceptability. The first step seeks to quantify agricultural sustainability to determine which site-specific sustainability variables are taken into account. These sustainability variables can be roughly classified into three clusters, corresponding to the three perspectives on agricultural production. Smyth and Dumanski [23] proposed an FESLM. The FESLM, based on logical pathway analyses, provides a systematic procedure for identification and development of indicators and thresholds of sustainability. The FESLM was developed by an IWG as a recommended procedure by which sustainability of current and alternative land-use systems could be assessed. The FESLM is an extension of the framework for land evaluation (Food and Agriculture Organization of the United Nations [24]), except that evaluations are based on indicators of performance overtime, rather than land suitability. An assessment of sustainability is achieved by comparing the performance of a given land use with the objectives of the five pillars of SLM: *productivity*, *security*, *protection*, *viability*, and *acceptability* (Fig. 1). A classification for sustainability is proposed, and plans for future development of the FESLM are described.

The classes are a measure of the evaluator's confidence in the stability of factors affecting each system. The actual time limits (Table 2) are intended as a basis for further investigation.

The universality of FESLM allows for the development of a generic decision support system (DSS) which can be customized for local application by using indicators and criteria of local importance. The SLM indicators table provides the threshold, and their quantitative and qualitative ratings. Their score and ranks have been assigned according to the type of indicator (strategic, cumulative, or suggestive). Based on the knowledge-base, the rule-base for SLM indicators has been established. The trend of SLM indicators over time, in combination with their

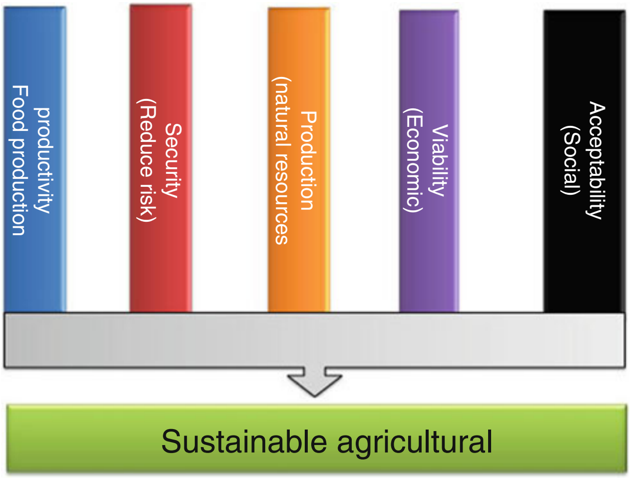

Fig. 1 Five pillars of sustainable agriculture

Table 2 Classes of sustainability proposed in the FESLM (source: [23])

	Classes	Confidence limits (year)
Sustainable	1. Sustainable in the long term	>25
	2. Sustainable in the medium term	15–25
	3. Sustainable in the short term	7–15
Unsustainable	1. Slightly unstable	5–7
	2. Moderately unstable	2–5
	3. Highly unstable	<2

threshold values, helps the evaluation of the sustainability of land management practices. The knowledge-base and rule-base act as the backbone of the DSS-SLM. The inference engine helps in processing the knowledge-base and rule-base of SLM indicators. Raise et al. [25] had developed the SLM indicators under the FESLM framework by conducting three case studies in Indonesia, Thailand, and Vietnam. In addition, they used the SLM indicators by developing an expert system based DSS which provides an opportunity to test and operationalize the FESLM concept for practical use. The same author's integration of many subsystems, including data bases, GIS, analytical tools, expert systems, simulations, and a user interface. To ensure proper integration, all software subsystems must follow a unified framework and standard. To make any system extendible and easily modifiable, the code should be modular and consistently commented, indented, and structured [26]. A schematic of the international board for soil research and management (IBSRAM) DSS-SLM under development is given in Fig. 2 (Table 3).

The indicators of SLM were developed along the five pillars of FESLM [25] and these indicators were modified and adapted for Egyptian condition by El-Nahry [28].

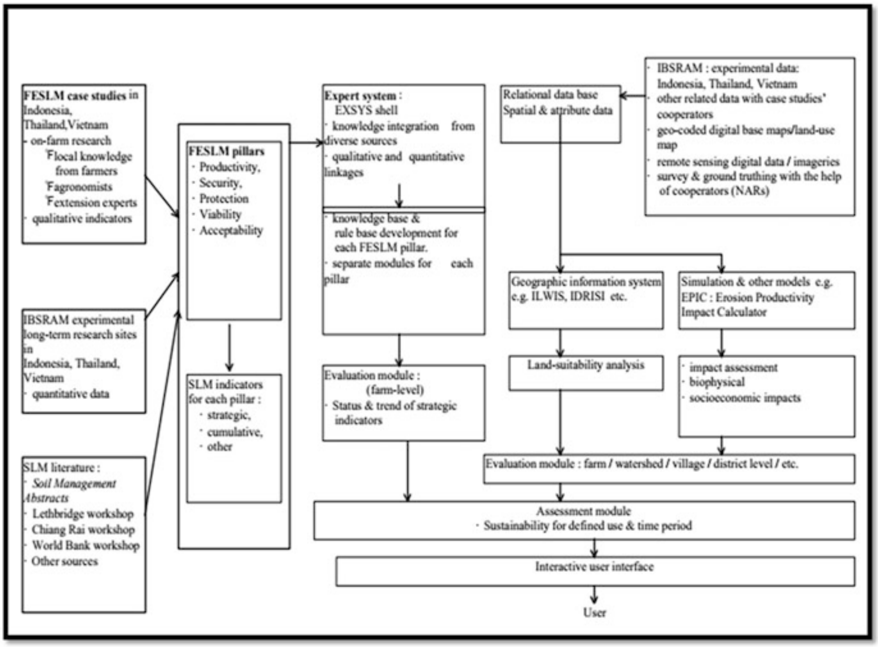

Fig. 2 Schematic representation of the international board for soil research and management (IBSRAM) DSS-SLM (source [25])

Table 3 Sustainability index [27]

Values	Land-use/management status	Class
0.6 to 1	Meet the sustainability requirements	1
0.3 to <0.6	Marginal but above the threshold of sustainability	2
0.1 to >0.3	Marginal but below the threshold of sustainability	3
0 to <0.1	Do not meet the sustainability requirements	4

Sustainability index has been obtained by multiplication of the five pillar indicators. Obviously, the multiplication results vary between 0 and 1. The closer value to 1 is considered the higher degree of the sustainability Tables 4, 5, 6, 7, and 8.

Many Egyptian authors have used remote sensing and GIS for mapping those five pillars (productivity, security, protection, economic viability, and social acceptability) in different areas in Egypt to estimate their accuracy under the Egyptian situations [27, 29–31].

The obtained multiplication results that reflected the degree of the agriculture sustainability are divided into four sustainability classes:

1. Land management practices meet sustainability requirements (from 1 to 0.6) (Table 3).
2. Land management practices are marginally above the threshold for sustainability (from 0.6 to 0.3).

Table 4 Criteria of productivity indicators: [25]

Indicators	Type[a]	Threshold	Qualitative ranking	Quantitative ranking	Score (a)	Rank (b)	Value ($a \times b$)
Yield	1	>25% or more Yd. reduction of the average of community	Yd. reduction: High	>25%	10	10	100
			Medium	10–25%	10	5	50
			Low	<10%	10	7	70
Soil color: Organic C	1	<1.2%	High: Dark soil	>1.2% (Yd. red. 0%)	10	7	70
			Medium: Brown soil	1–1.2% (Yd. red. 0–20%)	10	5	50
			Low: Yellowish	<1% (Yd. red. >20%)	10	7	70
Plant growth and leaf color: Soil nutrient N	2	<0.5%	High: Dark green leaves healthy, vigorous growth	>0.5%	7	7	49
			Medium: Color normal, moderate growth	0.2–0.5%	7	5	35
			Low: Yellowish leaves, stunted growth	<0.2	7	7	49
P	2	>15 ppm	High: Growth normal, color normal	>15 ppm	7	7	49
			Medium: Growth normal	8–15 ppm	7	5	35
			Low: Older leaves purple, stunted growth	<8 ppm	7	7	49
K	2	>90 ppm	High: Normal growth	>90 ppm	7	5	35
			Medium: Normal plant growth	60–90 ppm	7	5	35
			Low: Leaves yellowish from tip running along edge, and further expand, older leaves show symptoms first	<60 ppm	7	10	70

[a]Indicator's type and their score: strategic (1) = 10; cumulative (2) = 7; suggestive (3) = 3; relative ranking: 1–10. Value = score × rank

Table 5 Criteria of security indicators: [25]

Indicators	Type[a]	Threshold	Qualitative ranking	Quantitative ranking	Score (*a*)	Rank (*b*)	Value (*a* × *b*)
Average annual rainfall (amount and period) (ET by penman and Montieth)	1	<1,200 mm, spread over 4/8/2017 months	Low: Yd. red. >25%	<1,200 mm, <4 months	10	10	100
			Normal: Yd. red. 0%	>1,200 to <2,400 mm during 4–8 months	10	7	70
			V. High Yd. red. >25%	>2,400 mm, >8 months	10	10	100
Biomass: (% of crop residue) ploughed back to land	2	<50% of cop residue >3 years continuously	High amount for long time	>50% for >3 years	7	7	49
			High amount for short time	>50% for <3 years	7	5	35
			Low amount for long time	<50% for >3 years	7	5	35
			Low amount for short time	<50% for <3 years	7	5	35
Drought frequency	1	<800 mm RF	No drought: Yd. red. 0–25%	Rainfall >800 mm	10	7	70
		>2 years consecutively	Drought: Yd. red. >50%	Rainfall: <800 mm for >2 years	10	10	100

[a]Indicator's type and their score: strategic (1) = 10; cumulative (2) = 7; suggestive (3) = 3; relative ranking: 1–10. Value = score × rank

3. Land management practices are marginally below the threshold for sustainability (from 0.3 to 0.1).
4. Land management practices do not meet sustainability requirements (<0.1) (Fig. 3).

5 Case Studies in Egypt

There are several studies on sustainable agriculture under Egyptian condition. These studies discussed the sustainability constraints such as salinity and alkalinity, lack of infrastructure, and credit utilization. Nawar [31], Abdel Kawy [29], and Mohamed et al. [30] focused their scope of studies on assessment of sustainability factors for

Table 6 Criteria of protection indicators: [25]

Indicators	Type[a]	Threshold	Qualitative ranking	Quantitative ranking	Score (a)	Rank (b)	Value ($a \times b$)
Erosion	1	4.5 cm or more during last 7 years	Low: Yd. red. 0–10%	<0.7 cm	10	7	70
			Medium: Yd. red. 10–25%	0.7–4.5 cm	10	5	50
			High: Yd. red. >25%	>4.5 cm	10	10	100
Cropping system and extent of protection	2	Double cropping	With hedge row: High: Double cropping	Extent of protection: 80–100%	7	10	70
			Medium: Mono-cropping		7	7	49
			Without hedge row:	50–80%			
			Medium: Double cropping	50–80%	7	7	49
			Low: Mono-cropping	0–50%	7	5	35

[a]Indicators type and their score: strategic (1) = 10; cumulative (2) = 7; suggestive (3) = 3; relative ranking: 1–10. Value = score × rank

agricultural utilization through integrated biophysical, economic viability, and social acceptability using GIS special model in the different areas in Egypt. Mohamed et al. [30] used FESLM to assess agricultural sustainability conditions in north Sinai region. Moreover, they illustrated that an area about 7% of the northern part of Sinai are marginally below the threshold for sustainability where the sustainability values are ranging between 0.1 and 0.3, while the rest of the area does not meet sustainability requirements where the sustainable values <0.1 (Fig. 4). The same authors suggested some recommendations to improve sustainability condition in north Sinai as follows:

- Improved infrastructure in northern Sinai, which includes roads and canals.
- Use of effective management of soil for water and wind erosion control, based on sensible soil conservation practices.
- Attention to social and economic factors that attract people to this area.
- Education to farmers about sustainable agricultural practices so as to be more familiar with improved sustainable practices that will improve their productivity.
- Use of precision agriculture as much as possible in this region as this technique will maximize agricultural yield.

Table 7 Criteria of economic viability: [25]

Indicators	Type[a]	Threshold	Qualitative ranking	Quantitative ranking	Score (a)	Rank (b)	Value ($a \times b$)
Benefit cost ratio	1	B/C ratio 1.00 or more	High	>1	10	10	100
			Medium	1–0.8	10	7	70
			Low	<0.8	10	5	50
Percentage of off-farm income	2	25% or more	High	>25%	7	7	49
			Medium	10–25%	7	5	35
			Low/none	<10%	7	7	47
Difference between farm gate price and nearest main market price	2	>15%	High	>50%	7	7	49
			Medium	15–50%	7	5	35
			Low	<15%	7	7	49
Availability of farm labor	2	1 + 1 man year	High	>2 man year	7	7	49
			Medium	1–2 man year	7	5	35
			Low	1 man year	7	7	49
Size of farm holding	3	1 ha	High	>1 ha	3	7	21
			Medium	0.5–1 ha	3	3	9
			Low	<0.5 ha	3	5	15
Availability of farm credit	3	50% or more of the demand	High	>50%	3	5	15
			Medium	25–50%	3	3	9
			Low	<25%	3	3	9
Percentage of farm produce sold in market	2	50% or more	High	>50%	7	5	35
			Medium	25–50%	7	3	21
			Low	<25	7	3	21

[a]Indicator's type and their score: strategic (1) = 10; cumulative (2) = 7; suggestive (3) = 3; relative ranking: 1–10. Value = score × rank

- Promotion of greater public awareness of the role of people's participation and people's organizations, especially women's groups, youth, indigenous people, local communities, and small farmers, in sustainable agriculture and rural development.

El-Sharkiya governorate of Egypt was better than Sinai where about 31% of El-Sharkiya territory did meet sustainability requirements with score ≥0.65, and 12.6% of the territory represented marginally above the sustainability threshold. Meanwhile, about 48% of El-Sharkiya governorate did not meet sustainability requirements with index values >0.1 [29] as displayed in Fig. 5. The authors used SLM model. Where, they integrated biophysics and socioeconomic elements approach through biophysics elements (productivity, security, and protection) and socioeconomic aspects (economic viability and social acceptability) for the purpose of combating and tackling sustainability constraints that preclude the agricultural development to reduce them to acceptable levels of mass production endeavors.

Table 8 Criteria of social acceptability indicators: [25]

Indicators	Type	Threshold	Qualitative ranking	Quantitative ranking	Score (a)	Rank (b)	Value ($a \times b$)
Land tenure	2	Full ownership of land	1. Full ownership		7	7	49
			2. Long-term user rights		7	5	35
			2. No official land title		7	7	49
Support for extension services	3	One extension worker per 100 farms	1. Full extension support		3	7	21
			2. Very low extension support		3	5	15
			3. No extension support		3	7	21
Health and educational facilities in village	3	One school and one health center	1. There are adequate educational and health facilities in the village		3	7	21
			2. There is shortage of educational and health facilities		3	5	15
			3. The are no educational and health facilities		3	7	21
Percentage of subsidy for conservation packages	2	50% subsidy	1. There is sufficient subsidy available	1. 50% or more	7	5	35
			2. There is limited subsidy	2. <50%	7	5	35
			3. There is no subsidy		7	5	35
Training of farmers about soil and water conservation	3	Training once in 3 years	1. There has been sufficient training	1 Once or more in 3 years	3	5	15
			2. There has been no training	2. No training	3	5	15
Availability of agro-input within 5–10 km range	3	Easy access to agro-chemicals and seeds etc.	1. Agro-inputs are available as per requirements		3	5	15
			2. Inputs are available in limited manner		3	5	15
			3. No inputs are available		3	5	15
Village road access to main road	3	Village road has full access to main road	1. Village road has full access to main road	1. 80–100% road ready	3	7	21
			2. Limited access to main road by motor	2. 50–80% road ready	3	5	15
			3. No access to main road by motor	3. <50 road ready	3	5	15

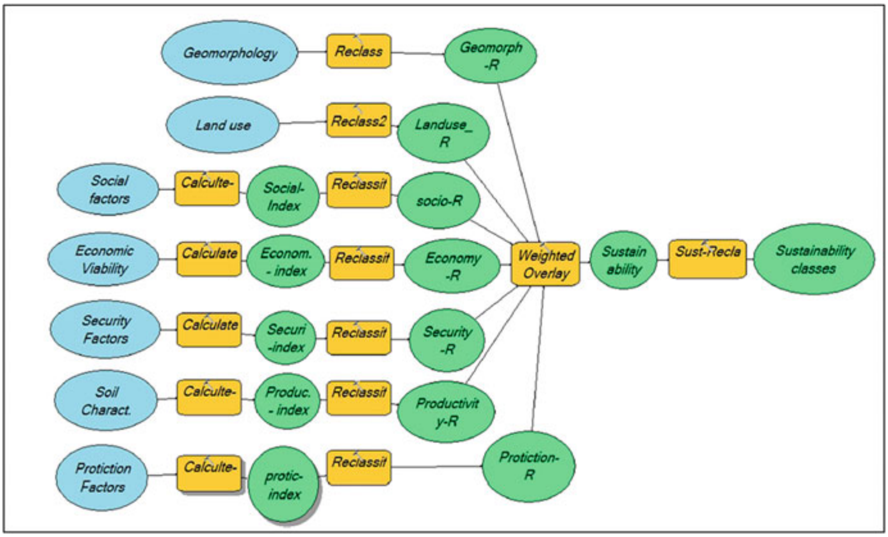

Fig. 3 Sustainable agricultural special model (SASM) (source, [30])

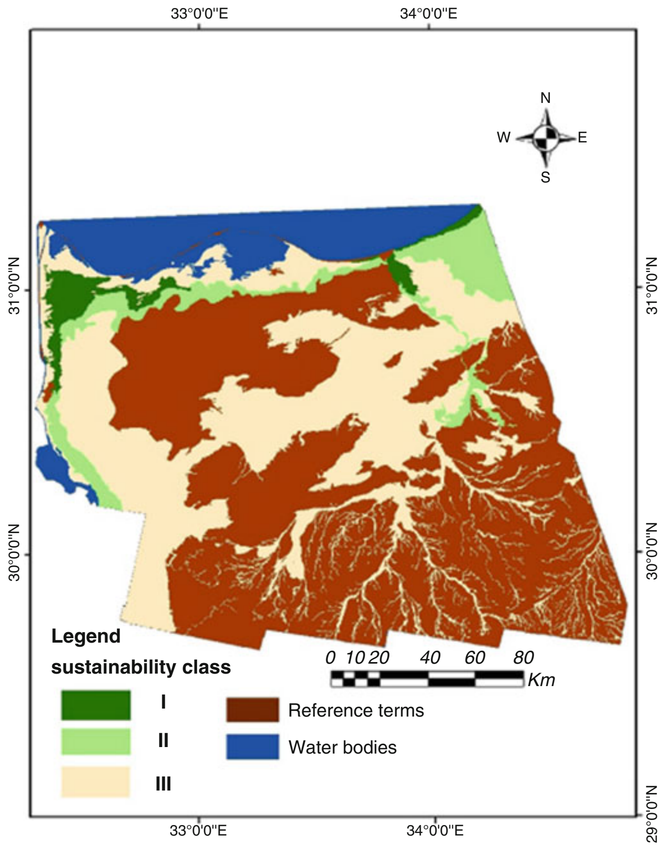

Fig. 4 Sustainability classes in North Sinai

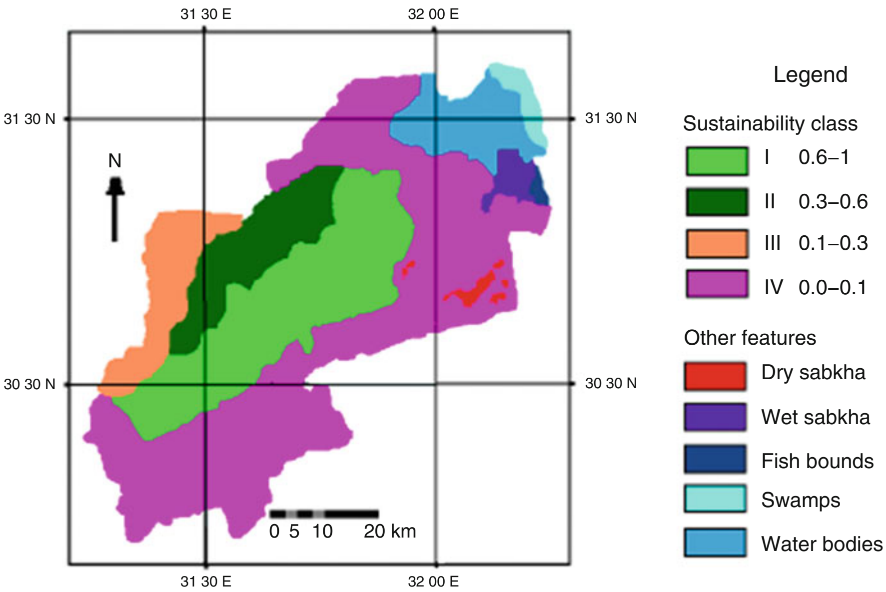

Fig. 5 Sustainability classes in El-Sharkiya governorate (source, [27])

Kafr El-Sheikh Governorate has been classified into two different class types, the first is the lands that are marginally below the requirement of sustainability and the second are those lands that do not meet sustainability requirements [29] as shown in Fig. 6. The sustainability constrains in the studied area are related to the soil productivity, economic viability, and social acceptability.

6 Conclusion

Sustainable agriculture is increasingly viewed as a long-term goal that seeks to overcome problems and constraints that confront the economic viability, environmental soundness, and social acceptance of agricultural production system in Egypt. While there are many definitions of sustainable agriculture, most of them espouse the same elements of productivity, profitability, conservation, health, safety, and the environment. There is a general agreement that sustainable development includes environmental, economic, and social dimensions. SLM combines several technologies, policies, and activities aimed at integrating socioeconomic principles with environmental concerns to simultaneously satisfy the five pillars of SLM. In conclusion, the five pillars of SLM could be used to protect the potential of natural resources and prevent degradation of soil and water quality, to reduce the level of

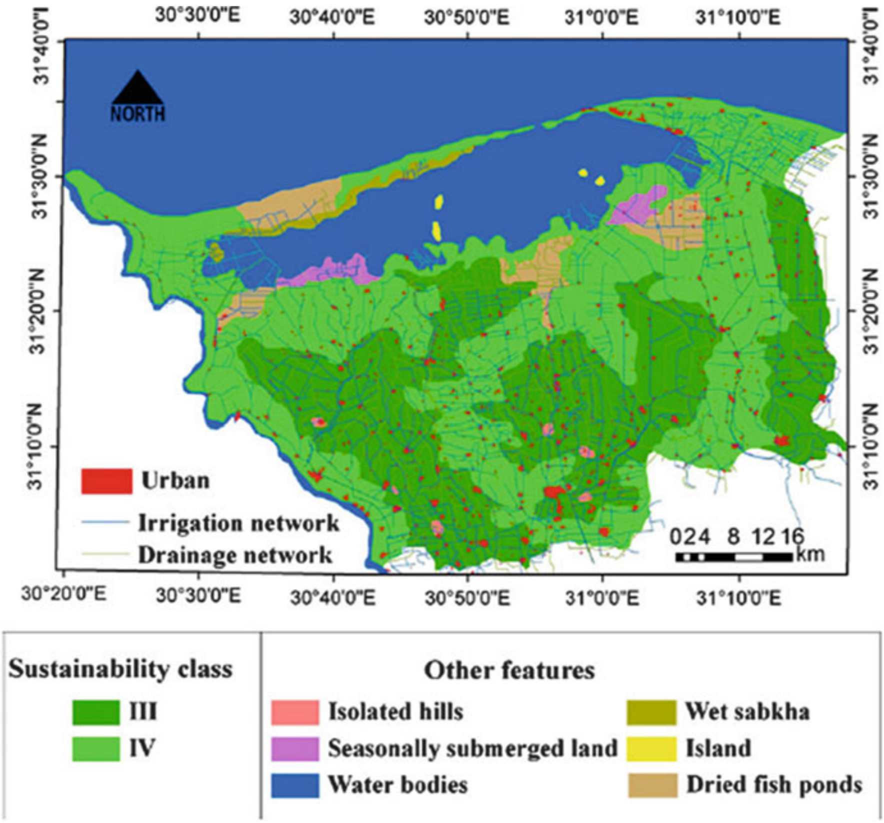

Fig. 6 Sustainability classes in Kafr El-Sheikh governorate (source, [29])

production risk, to be economically viable to maintain the production services, and to be acceptable.

7 Recommendation

The authors recommend that for sustainable agriculture, there is a consensus on several basic features of sustainable agriculture in Egypt that could contribute to 2030 Egyptian sustainability plan: (1) maintenance of environmental quality, (2) stable plant and animal productivity, and (3) social acceptability. In addition, SLM in agriculture is a very complex and challenging from the point of view of enhancing the biophysical, socioeconomic, and environmental concerns that would enhance the land potentiality for sustainable agriculture. The SLM is a good strategy to sustain development to overcome the loss of soil productivity from excessive erosion/ intensive cultivation and associated plant nutrient loss/depletion; surface and groundwater pollution; impending shortages of nonrenewable resources; and low farm income due to low commodity prices and high production costs.

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Implication of Geo-Informatics (GIS/RS) on Agricultural Irrigation Management: The State of the Art

Maha Elbana, Noura Bakr, and Fawzi Karajeh

Contents

Abstract The agricultural sector is the highest water consumer worldwide. Its production is the essential pillar in world's food security. Limited water resources are the major constraint in an agricultural production system. Better application of irrigation water will result in increased water and land productivity for the planted crops. Precision irrigation is one of the promising keys to solve this dilemma. It allows applying the exact needed amount of water in its optimal place at the right time. Yet, this requires a huge information database to be accurately able to apply precision irrigation. The traditional trial-and-error technique in agricultural experiments to improve land and water productivity is time-consuming and sometimes is economically unaffordable. Thus, there is a need to develop more cost-effective and

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accurate tools to correctly survey world's natural resources and its most sustainable exploitation. Geo-informatics implication in combination with suitable decision support systems plays a relevant role in water management in agricultural sector, especially when applying precision irrigation and farming techniques.

This chapter aims to provide an overview about the implication of geo-informatics (with a special focus on geographic information systems and remote sensing) in irrigation water management on both local level (Egypt) and international level. Although geo-informatics applications for agricultural management have been used since the early 1980s, still there is a place for further research to maximize the benefits of its use. Public involvement is critically needed to ensure sustainability of applied water management programs using geo-informatics.

Keywords Geo-informatics, GIS, Irrigation management, Precision irrigation, Remote sensing

1 Introduction

In September 2015, the United Nations issued the 17 sustainable development goals to make the world better by ending the poverty and offering food and peace for everyone. At least eight of those goals are directly or indirectly related to agriculture, namely, no poverty, zero hunger, responsible consumption and production, life blow water, life in the land, clean water and sanitation, affordable and clean energy, and climate action.

The agricultural sector and agribusiness is the main income source for about one-third of the world's population, globally. In Egypt, about half to two-thirds of the Egyptians live or are employed in the rural areas and depend directly on the agricultural sector for their livelihood [1]. Figure 1 shows the percentage of Egyptian population who are working in the ruler area over the last 55 years based on the World Bank data inventory. There is a reduction in the number of population percentage by around 4% from 1960 to 1975. After that period the percentage is almost constant between 56 and 58%.

Agriculture is the highest freshwater consumer compared with other economic activities. Agricultural activity consumes around 70% of the world's freshwater resources [2]. Agriculture consumption of water in Egypt varies from 80% [3] to 85% [4], respectively. Thus, to achieve sustainable agricultural development, maximizing crop and water productivity is essentially required. Water productivity[1] has been increased in some crops, i.e., rice and wheat by at least 100% between 1961 and 2001 [5]. This growth was mainly due to noticeable improvements in crop varieties and better management practices that resulted in crop yield increase. However, it is anticipated that the world population will be increased by two billion in 2030 [5]. This anticipated challenge upsurges the call for further development

[1]Water productivity is a term that refers to more output per unit of applied water.

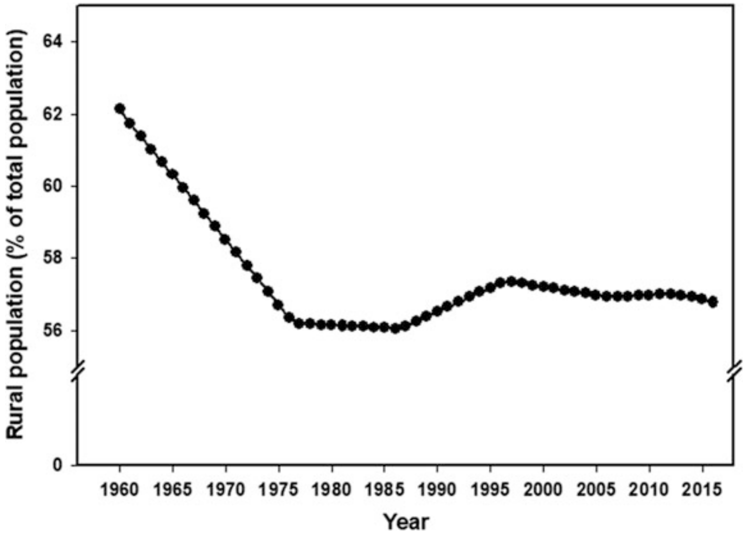

Fig. 1 The percentage of Egyptian population who are working in the rural areas from the total population of Egypt (created by author)

actions to increase water productivity [6]. Also, the majority of developing countries suffer from water shortage and/or lack of crop-water productivity mainly because of the observed maladministration of natural resources on both on-farm and irrigation district levels [7].

Egypt, for example, is characterized by its limited natural water resources that are presented mainly on river Nile with its constant annual share of 55.5 billion m^3. The evident increase of the Egyptian population from 76.5 million in 2006 to 90.1 million in 2016 [8] resulted in a visible decrease in the annual available freshwater per capita. According to the Egyptian Ministry of Agriculture and Land Reclamation [9], the annual per capita share of water decreased from 850 m^3 in 2006 to 700 m^3 in 2011, and it is expected to drop down to 500 m^3 by 2030. All of those amounts of water are already below the water poverty line of 1,000 m^3 per capita per year.

Besides the exponential increase in Egypt population [10], a serious decreasing of water resources in Egypt is expected in the future. This is mainly because of (1) climate change and greenhouse effect [2], (2) lack of any improvement of water availability, and (3) other international political issues, i.e., the Ethiopian Dam [11]. Accordingly, there are two aspects that should be considered to meet the demand and water deficit in Egypt; one is to search for another source for irrigation such as treated wastewater which can offer about 2.4 billion m^3/year [12] and replaced the conventional irrigation by modern irrigation technology. Therefore, maximizing water and land productivities are considered the foremost challenges the world faces nowadays for more sustainable food security especially, in arid and semiarid countries, i.e., Egypt. On the other hand, several researches have been conducted to study improving water and land productivities as important tools for food security [13–18].

Surface irrigation, as a traditional irrigation method, is responsible for losing a significant amount of water that may reach up to 60% or more if it is not managed properly. Reducing the losses of applied irrigation water shall lead to an increase in water productivity. This improvement in water productivity can be achieved by several ways such as, replacing plant varieties and improved high yielding ones, optimizing production inputs such as fertigation, introducing best agronomic and cultural practices, and implementing improved irrigation method to deficit irrigation, among others [15]. In addition, irrigation system modernization accompanied by better coordination between mangers, users, and/or stakeholders should be considered as well to improve water productivity [19].

Despite the noticeable implication of geo-informatics in agricultural system production worldwide, relatively fewer reports and studies focused on its application in on-farm water management.

The presented chapter reviews literature by local (in Egypt) and international researchers on agricultural irrigation management applying geo-informatics (with a special focus on GIS and RS technologies) as an effective tool to improve water and land productivity.

2 History of Geo-Informatics' Involvement in Agricultural Irrigation Management

On the international level, geo-information techniques have been applied since the early 1980s. The California Department of Water Resources worked since 1982 until now in cooperation with the Office of Water Use Efficiency (OWUE) to build up the California Irrigation Management Information System (CIMIS) [20]. This system aims at producing a geospatial map for reference evapotranspiration (ET_o) and a set of software programs for irrigation scheduling, disease risk management, soil moisture, water quality, etc.

The FAO [21] as well set an agroecological zoning methodology and supporting software AEZWIN in cooperation with the International Institute for Applied Systems Analysis (IIASA) for application at global, regional, national, and subnational levels. The system is considered as a useful tool for land resources assessment [21, 22]. However, the obtained results by FAO and IIASA are based on very coarse resolution maps (scale 1:5,000,000). The resulted smaller scale maps cannot reveal the actual status of land degradation. This provokes certain concerns regarding using such models and maps on agriculture. In 2007, Soil and Terrain Database Program (SOTER), based on soil parameters, had been updated filling the gaps in its soil profile data. Soil parameter estimates for Central Africa (Scale 1:1 million) and the Democratic Republic of the Congo (Scale 1:2 million) have been developed [23].

Moreover, the International Water Management Institute (IWMI) developed the World Water and Climate Atlas. The Atlas was mainly based on data assembled from different weather stations distributed worldwide for the period 1961–1990. The produced Atlas aimed mainly at determining the most proper regions for rainfed and irrigated agriculture. It also provides inputs for river basins hydrological and crop modeling [24]. Nevertheless, the provided Atlas outputs do not include recommendations or predictions for agricultural practices, i.e., irrigation scheduling or disease risk management.

Later on, maps resolution has been improved radically. The European Space Agency (ESA) adopted an initiative to produce a 300 m global land cover map called GlobCover based on the geo-informatics. The success of this initiative resulted in further improvement and more updated database producing GlobeCorine 2005 and 2009. The produced database and maps are available for free download through the ESA portal [25].

Also, many other researches on applying geo-informatics in agriculture and irrigation management have been conducted. Bastiaanssen et al. [26] used geo-informatics for scaling up water productivity in irrigated agriculture for the Indus basin. The study revealed that water productivity tends to a constant value at a spatial scale of 6 million ha and higher. This was mainly because of the equity between water diversion and water depletion at this scale. As a result, this indicated the ability of the groundwater systems to regulate losses and reuse of water resources. They also demonstrated how images such as NOAA-AVHRR could provide a quick scan of parameters necessary for water productivity assessment.

Hellegers et al. [27] applied a combination of spatial land surface data with socioeconomic analysis to provide suitable indicators to support the decision-making in integrated water and environmental management in the Inkomati Basin in the eastern part of South Africa. Elbana et al. [28], as well, used the geographic information system (GIS) technology to set up a digital database for the actual status of treated wastewater reuse in agricultural irrigation in the province of Girona, Catalonia (Spain). The study revealed the ability to save 20% of conventional water consumed by agricultural sector to be directed for satisfying the urban sector. Their study was based on water quality specifications according to the Spanish Royal Decree 1620/2007, which regulates reclaimed effluent reuse in Spain.

Edlinger et al. [29] recreated the expansion and densification of the irrigated cropland in the Kashkadarya province, Uzbekistan, Central Asia using Landsat MSS and TM data from 1972/1973, 1977, 1987, 1998, and 2000. They interpreted the multitemporal normalized difference vegetation index (NDVI) data and crop phonological knowledge for tree classification. They concluded that the utilization of Landsat Archives in the Kashkadarya Province, Uzbekistan, was the first application of mapping cropland development in Central Asia over the past 40 years. They also proved that knowledge-based decision trees based on Landsat scale that are suitable for mapping cropland of agricultural landscape within desert and steppe zones.

The biennial bearing effect on coffee yield using MODIS remote sensing imagery has been studied in Brazil by Bernardes et al. [30]. They aimed to assess potential associations between coffee yield and MODIS-derived vegetation indices. The study revealed that the best correlation was found between the variation on yield and variation on vegetation indices. This was not enough to estimate coffee yield exclusively from vegetation indices.

Vancustem et al. [31] combined the existing land cover/land use datasets for cropland area monitoring at the African continental scale. Their study aimed to optimally integrate the best available cropland datasets in a consolidated product. They produced a map at 250 m resolution covering the whole Africa and another partially covering Niger and Nigeria both based on the expert visual interpretation of high-resolution images using GeoWiki tool. Moreover, Udelhoven et al. [32] used the near-infrared spectroscopy (NIRS) and hyperspectral remote sensing to retrieve the biomethane potential. They proved that the remote sensing method only works reliably close to the time of harvest when the dry matter content is at its maximum and becomes less variable.

In a case study of regional durum wheat yield estimation in Tunisia using 13 years of low-resolution SPOT-VEGETATION observations, Meroni et al. [33] have investigated the interactions among four different remote sensing biomass proxies. They were mainly characterized by increasing physiological meaning, and six different statistical models are relying on different hypotheses and using a varying number of degrees of freedom. The study assessed the progress of the adoption of more complicated biomass proxies and the trade-off between model sophistication and data accessibility. The study indicated that the best performance was achieved using the most physiologically sound remote sensing indicator (the phonologically tuned cumulative value of the absorbed photosynthetically active radiation) in conjunction with statistical specifications allowing for parsimonious spatial adjustment of the parameters.

Moreover, Lyle et al. [34] estimated the historical yield data for wheat at farm level by testing the temporal capability of Landsat imagery and precision agriculture technology. The results verified the potential benefit of using two high-resolution datasets to create robust wheat yield prediction models over different growing seasons. These results could be of great use to the agricultural decision-makers.

On the other hand, constraints do face the researchers who intend to use geo-informatics in agricultural management. One of the major constraints is the limited availability of actual and accurate dataset. The limited access to developers and scientists to the ground-truth information restricts the evaluation process of the produced technologies and models under different environmental settings and conditions [35]. Thus, there is an urgent need to set up an easy access networks to facilitate produced models' calibration and evaluation under different conditions. There is a need as well to allow geo-informatics' users to at least visualize information products in a simple way such as Google Earth [35].

At the national level, Egypt is valuing the role of geotechnology in agricultural management and innovation. El Kady and Mack [36] emphasized the requirement to set up a more sustainable cost-effective mean for data acquisition for the agricultural sector management in Egypt. They also pointed out remote sensing as a role player in the aforementioned data collection especially in the measurement of electromagnetic radiation reflected by vegetation, soil, water, and other features of the Earth's surface.

Processing of satellite imagery for agricultural purposes in Egypt was started as early as 1983 when the Remote Sensing Center of the Academy of Scientific Research conducted the first estimation of irrigated agricultural areas in Egypt using digital processing of Landsat multispectral scanner data [37].

In 1988, the National Oceanographic Institute (ION) in France produced a thematic map of El-Fayoum governorate, Egypt in cooperation with the Egyptian Survey Authority using SPOT imagery to obtain an accurate assessment of the cultivated area of El-Fayoum governorate [38]. According to Wolters et al. [39], the Egyptian Survey Authority in cooperation with the Consultants of Water and Environment, Rotterdam, The Netherlands, determined the total cultivated land area and the waterlogged, saline, and urban areas of El-Fayoum governorate using Landsat TM images. Yet, they concluded the difficulty of making a detailed crop map of this area because of the small field size and fragmented land use.

The International Institute for Land Reclamation and Improvement (IWACO), Rotterdam, The Netherlands in 1989 classified Landsat TM images of the Eastern Nile Delta and Valley between Beni Suef and El Minya for the Ministry of Public Works and Water Resources (MPWWR) [36].

Later, the Soil and Water Research Institute (SWRI) of the Agriculture Research Center (ARC), Ministry of Agriculture and Land Reclamation (MALR), Egypt, used the Landsat TM image to estimate the cultivated area in both Lower and Upper Egypt [40]. Bakr et al. [41] evaluated land capability in newly reclaimed areas in Egypt using geospatial model (Cervatana model). They indicated that using GIS has significantly improved spatial data handling and analysis and has enabled spatial modeling for terrain attributes. They also concluded that the coupling between modeling and GIS serves to improve land use planning and consequently enhance the decision-making process, especially in newly reclaimed areas.

Bakr et al. [42] monitored land cover changes in the Bustan 3 area (El-Nubaria, Egypt) using multitemporal Landsat images captured in 1084, 1990, 1999, 2004, and 2008. They used the hybrid classification approach and normalized difference vegetation index (NVDI) in their study. The results revealed that from 1984 to 2008, the Bustan 3 area of Egypt transformed the 100% of its barren land to 79% agricultural land which reflects the successful land reclamation efforts.

Egypt geographically can be classified into five main regions: Nile Valley, Nile Delta, Western Desert, Eastern Desert, and Sinai Peninsula (Fig. 2). Additionally, there are several who attempted to classify Egypt territory to different agroclimatic zones. First, it was divided into three main agroclimatic zones (Lower Egypt, Middle Egypt, and Upper Egypt) by Eid et al. [43]. In 2007, it was divided into nine zones: Coastal Zone, Central Delta, East and West Delta, Giza, Menia, Asyout and Souhag, North Quena, South Quena, and Aswan [44]. Later on, Ismail [45] divided the Egyptian territory into seven agroclimatic zones. The location of the

Fig. 2 The main geographical regions of Egypt territory (created by author)

Egyptian governorates is shown in Fig. 3. In 2011, a study was made to divide Egypt into five agroecological zones: the coastal region, the middle Delta region, the Middle Egypt region, the Upper Egypt region, and the newly reclaimed lands [46]. At the same period, El-Nahrawy [47] also classified Egypt to five agro-ecological zones: Baltim, Gemmeiza, Tahrir-Ismailia (those three in Nile Delta region), Beni Suef, Giza, and Mario-Aswan (this one involved Nile valley and desert oases) zone besides the stoney and mountainous desert. Additional attempt to classify Egypt territory to various agroclimatic zones was achieved by Khalil et al. [48] as they classified Egypt to eight different agroclimatic zones. Noreldin et al. [49] classified Egypt into seven agroclimatic zones based on the potential evapo-transpiration values those zones are matched with Khalil et al. [48] eight zones. The updated map for the locations of those zones is presented in Fig. 4.

In 2010, ICARDA GIS Unit team participated in developing the Climate and Drought Atlas for parts of the Near East [51]. The Atlas has been developed in cooperation with multiple international institution including (1) World Food Program (WFP), (2) Regional Center for Disaster Risk Reduction (RCDRR), and (3) the United Nations International Strategy for Disaster Risk Reduction (UNISDR). The developed Atlas covers Egypt, Jordan, Lebanon, the occupied Palestinian territories, and Syria with 344 climate maps at 30 arc-second spatial resolution (approximately 1 km^2). The developed maps represent the average climatic conditions expected for the incoming 30 years period, from 2010 to 2040

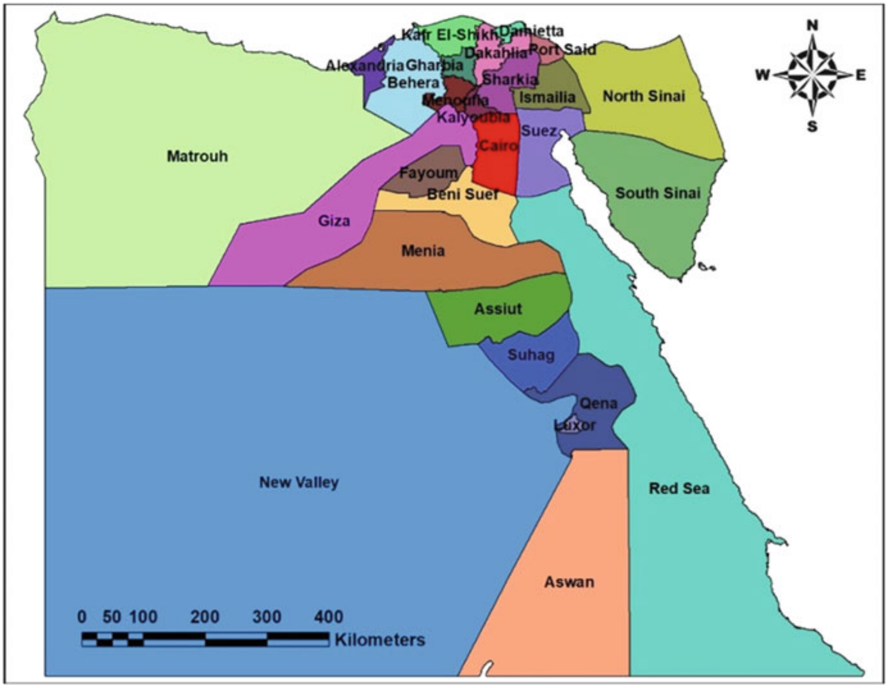

Fig. 3 The geographic location of Egyptian governorates (created by author)

under different scenarios, the severities and extents of historical droughts during the past century and trends of precipitation and drought as well as precipitation patterns during that period.

Bakr et al. [52] identified the most environmentally sensitive area to desertification in the Bustan 3 area (El-Nubaria, Egypt). They used the standard and adjusted Mediterranean Desertification and Land Use (MEDALUS) approach for years 1984 and 2008 in their study. They adjusted the MEDALUS factors for 2008 to obtain more reliable data at the local level under Egyptian conditions. The research study showed that about 78% of the study area is sensitive to desertification due to the impact of plant cover. After adjusting the MEDALUS model to fit the Egyptian conditions, it was found that the vulnerable area to desertification due to land cover parameter was increased to reach 89% of the study area. Thus, they recommended more attention to the most sensitive areas to desertification to achieve the most possible sustainable management for El-Bustan area, Egypt.

Elbana et al. [53] studied and mapped the spatial accumulation and distribution of heavy metals in Elgabal Elasfar farm (Egypt) using GIS facilities as a consequence of long-term irrigation with domestic wastewater. They reported that the concentration of studied heavy metals (Pb, Cd, Cu, and Ni) in water samples were less than the permissible level for irrigation set by many organizations. Investigated concentrations were higher than allowed levels by (1) the EEAA Executive

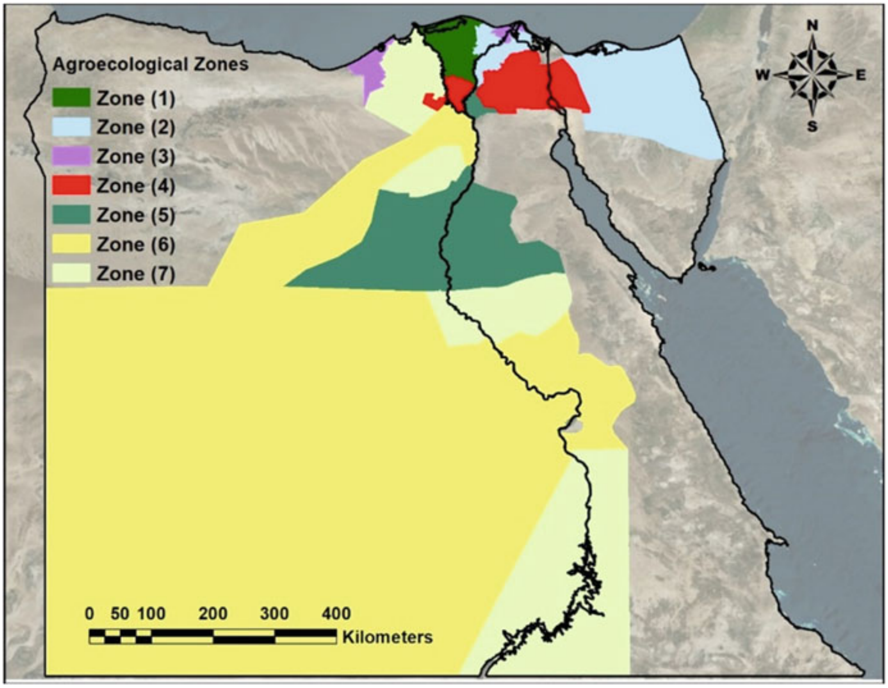

Fig. 4 Classification of Egypt into seven agroclimatic zones. Updated by authors from Khalil et al. [50] and Noreldin et al. [49]

Regulation of the Egyptian Law 4/1994, (2) Egyptian code (ECP 501, 2005), (3) WHO guidelines for the safe use of wastewater, (4) excreta and gray water, and (5) the FAO guidelines for water quality for agriculture, irrigation, and drainage (Paper 29). They also pointed out that Cd concentration was critical in the surface layer. Meanwhile, they indicated that the concentration of heavy metals versus soil depth revealed that the Pb accumulation was mainly in the topsoil where extensive mobility and potential hazard for soil contamination were observed for Cu < Ni < Cd.

A remote sensing study in the northwestern Nile Delta about the Irrigation Improvement Project (IIP) for monitoring winter crops under changing irrigation practices was held between 1997/1998 and 2002/2003 [54]. The study was performed under an assignment of the Egyptian MWRI and financed by the Kreditanstalt fur Wiederaufbau (kfw), Frankfurt am Main, Germany. The study was held for three command areas. First area was El-Mahmoudia command area in El-Behira governorate, Egypt that serves 66,674 ha, 86.8% of which is cropped. Second, El-Wasat command area in Kafr El-Shikh governorate that serves 29,141 ha, 86.1% of which is cropped. The third area was El-Wasat canals in Kafr El-Shiekh governorate as well and serves 19,829 ha (87.7% are cropped). The study concluded that wheat-cultivated area has increased from 1997/1998 to 2002/2003 for both improved and non-improved canal command areas. In the winter season of 2002/2003, a decrease of overall consumptive use (ET_c) by 12% was observed due to the different meteorological conditions in 1997/1998 as compared to 2002/2003. The study proved as well an increase of water productivity for all crops from 1997 to 2003, with a slightly larger increase in the IIP-improved areas. It was also pointed out that wheat crop-water productivity was increased from 1.34 in 1998 to 1.50 in 2003, which is larger than the worldwide water productivity for wheat of 1.08.

The MWRI contracted as well with a team of experts (Misr Consult) to prepare an environmental assessment study for the Integrated Irrigation Improvement and Management Project (IIIMP) during the period from July to September 2004 [55]. The study presented key findings and recommendations to relevant aspects to the following:

1. The proposed IIIMP physical interventions in each command area
2. The baseline environmental profile of each command area including existing environmental challenges
3. The key potential environmental impacts of the IIIMP
4. The proposed Pest Management Plan (PMP)
5. The proposed Environmental Management Plan (EMP)
6. Other institutional and organizational aspects of the environmental component
7. The proposed environmental component's budget

3 Geo-Informatics for Agroecological Characterization

Creating accurate and updated geospatial datasets for agricultural lands are critically needed for more sustainable on-farm water management and food security. The use of geo-information techniques, i.e., remote sensing and GIS, is confirmed as efficient tools to override the majority of difficulties encountered in the collection of a large amount of data [56]. This will result in more sustainable on-farm management especially for irrigation and drainage systems [36]. The idea is to use this technique for dividing the agricultural land and/or the world to different agroecological zones (AEZs). Each zone has its climate, soil, crop, and water database to help irrigation scheduling and improve water use efficiency and water and land productivities.

Agroecological zoning is considered as one of the most relevant approaches for agriculture planning and development. This is because the success or failure of any farming system depends primarily on the surrounding agroclimatic resources [45]. According to the Inland Valley Consortium [57], the importance of characterizing different territories on agroecological base is derived from the fact that, at different scales, there exist a difference in soil structure, soil nutrient distribution, and water dynamics, among other factors, i.e., population density, climate, geology, market accessibility, etc. These factors are important for modern agriculture research and development especially for technologies such as plant genetics, farming practice, and appropriate machinery. As trial-and-error technique is simply too expensive, time-consuming, and wasteful of resources, the agroecological characterization identification will be an efficient tool for setting scientific research priorities for more sustainable improvement and development to the targeted agricultural system. In addition, the results of the agroecological characterization will be the basis for technology transfer.

However, in order to achieve the highest benefit of remote sensing technology, the data must be inherently sound. This implies an ongoing need for calibration, validation, stability, monitoring, and quality assurance [25].

4 Geo-Informatics and Precision Irrigation

With the increased stress in freshwater especially in arid and semiarid areas, the management of irrigation process is greatly required with a high level of precision to minimize the water input and adverse environmental impacts while maximizing water productivity [58]. During the 1990s, the precision agriculture or site-specific management has grabbed the attention of all scientific community. The idea is to break out the field into smaller units and deal with each unit separately instead of dealing with the field as one unit as in conventional agricultural practice [59]. This should result at the end in maximizing the benefits of water and land productivity.

The term precision irrigation started to take its relevance during the early 2000s. It simply refers to applying the right amount of water to the plant in the right place at the right time for improving crop-water productivity and increasing yield. According to Evans et al. [60], precision irrigation is applying a precise amount of water at the correct time in a uniform way across the field.

The application of precision irrigation system needed integrating data about crop-water requirements, soil characteristics, irrigation scheduling, and high-tech irrigation equipment [58]. The precision irrigation term and techniques have been developed over time (Irrigation New [61]). At the first generation, the precision irrigation was depended on dividing the field into sectors (sector control) and was mainly applied in central pivots. In this case, the central pivot was divided into sectors; each sector is planted with the different crop which means different water requirement. The main idea of this technique is to control the speed of pivot movement to control the depth of applied water in each sector.

Later on, the technique has been developed to be based on segment control instead of sector control. In this case, the land has been split into smaller segments. Irrigation water, in this case, was controlled by banks of sprinklers. Each bank can control the entire segment or even part of it. Nowadays, precision irrigation has been developed to a full variable rate irrigation control technique. In this method, irrigation field could be divided into different zones based on soil properties and water content. The irrigation applied by controlling each sprinkler separately which allows to adding water to different zones at different timing and depth as necessary. Figure 5 shows the difference in shape among sector, segment, and full variable rate irrigation control techniques according to (Irrigation New [61]).

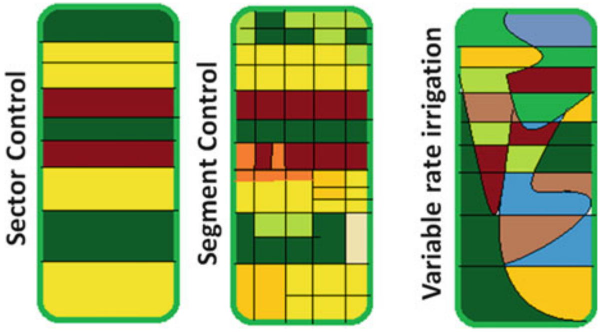

Fig. 5 Evolution in precision irrigation controlling techniques. Simplified and updated based on Irrigation New Zealand [61]

Dalezios et al. [62] used both field measurements and geo-informatics (GIS/RS) including image filtering and image processing to precisely divide a planted cotton field into different zones. Each zone shares similar soil properties and organic matter content. The target of this work was to precisely add water and fertilizers per location/zone as needed to reduce water and fertilizer inputs to the system. They concluded that applying WorldView-2[2] is a useful tool to extract the crop area and estimate crop-water requirements.

El Nahry et al. [46] studied the economic and environmental viability of using remote sensing and GIS techniques in precision irrigation. The research has been conducted in irrigated maize field on pivot system with total area 153.79 acre in Ismailia province (Egypt). They indicated that applying geo-informatics in precision agriculture could be a helpful tool in simplifying data collection and analysis. This resulted in better and rapid implementation to management decisions. They also found that applying precision farming (irrigation and fertilization) provoked saving 93,718 m^3 (~600 m^3/acre) compared to traditional farmer practice. Yet, the cost of implementing precision irrigation was higher than the traditional farmer practice. However, the total revenue (returns-costs) was in favor to applying precision farming. A total return increase of ~30% was found applying precision farming compared to traditional farming practice.

Hedley et al. [63] used an electromagnetic induction mapping system to collect soil conductivity data in real time at high resolution in combination with geo-statistical analysis to divide the field study into different soil management zones. They aimed to determine the potential benefit of applying precision irrigation to different pastoral and arable production soils in New Zealand. They compared two irrigation scheduling. One of them is applying uniform rate irrigation, and the second is variable rate irrigation. Fields have been irrigated only when soil zones reached a critical soil moisture deficit. They found out that applying precision irrigation to the field resulted in saving 8–21% of irrigation water and decreasing drainage and runoff by 19 and 55%, respectively. However, the utmost profitability

[2]WorldView-2 is a digital globe satellite sensor launched in 2009. It delivers a panchromatic mono- and stereo satellite image data of 0.46 m. More details could be encountered on https://www.satimagingcorp.com/satellite-sensors/worldview-2/.

of applying variable rate irrigation will be achieved when then the farmers dominate the idea of knowing a small quantity of irrigation water could be applied without affecting the commercial quality of their crop under the condition of knowing the planted crop-water stress threshold [64]. Nevertheless, the majority of developed techniques for precision farming including precision irrigation in addition of being highly expensive [65], they have been developed ignoring the knowledge levels and skills of local farmers [66]. On the other hand, Lea-Cox [67] counted a number of indirect economic benefits of applying precision irrigation such as reducing disease incidence, lowering fungicide costs, and minimizing nutrient runoff and groundwater consumption. Policymakers and extension services should consider conducting farmer capacity building and training on how to use the developed techniques to increase their farm revenue. More investigation should be applied in order to produce low-cost geo-information technology.

5 Agricultural Irrigation Management Technologies and Public Perception

No doubt that improving irrigated agriculture has both direct and indirect effects on poverty alleviation in rural areas through creating off-farm employment opportunities and develops investments in other activities such as infrastructure and markets [5]. The traditional agrarian people may be resistant to new management practices, especially who live in the developing countries. Thus, to apply new water management project, the stakeholders should be convinced of the benefits before the implementation of such activities.

Nevertheless, public perception and farmer involvement in improving irrigation practices are considered important factors that could accelerate or restrict water management projects on the agricultural sector at both on-farm and district levels. In other words, farmers and land users are key players who affect the success or failure of water and land productivities' projects directly. The low adoption of improved agronomic practice is mainly because of insufficient attention that is given to farmer participation and community action [68]. Ignoring land users' participation in development projects could result in a drastic failure for those projects even all other factors are suited well. According to FAO [5], ignoring public perception and land users' participation in soil and water conservation projects in Burkina Faso was one of the reasons for its failure until the early 1980s. Considering villagers' opinions and participation in the irrigation water management project in Yatenga region of the country's Central Plateau resulted in direct yield increase by 40% when testing and applying a number of new designed water harvesting techniques for irrigation purpose. Thus, it is recommended to engage farmers to national water resources and agricultural development plans to alleviate water scarcity and food insecurity [69].

Recently, the importance of farmer participation through the organization of water users associations (WUAs) in irrigation management is well accepted, and they are widely established [5]. Allam et al. [70] indicated that establishing WUAs and Irrigation Advisory Service (IAS) is the key element to improve irrigation water management and increase water productivity. However, to increase the chance of WUAs and IAS successfully meeting the objectives, they should be structured with due consideration to the indigenous knowledge and practices in water management.

In Egypt, the public awareness regarding lack water availability was increased [10]. However, several studies cited that the main reason for water availability shortage is the poor distribution rather than the lack of water supply [10, 71, 72]. Moreover, most of the institutions and research organizations are now aware to the importance of land user, and farmers interfere in any designed project or strategy. The Egyptian Ministry of Water Resources and Irrigation (MWRI) also recognized the important role of public perception and end-user effect on the success of any developed strategy. Therefore, and in partnership with USAID, the MWRI developed the water communication units (WCUs) in 1992 to provide a strong foundation to coordinate and launch public awareness programs [70]. The results and the level of success obtained as a result of the formation of WCU are not available.

The MWRI promoted as well a public awareness program to apprise people with the relevant role of water resources in the development plans and to encourage water users to positively participate in the decision-making process. Therefore, during the development of the new National Water Resources Plan, all stakeholders, both governmental (ministries, regional authorities) and nongovernmental (industry, water user organizations, etc.), are concerned with the development and use of Egypt's water resources involved [73].

Using of high-spatial-resolution imagery may allow monitoring of crop-growing season and crop-water use. Such information is highly appreciated by the professional farmers and/or decision-makers. This information should be easy-to-use so farmers, as main users for those types of information, can deal with it. Nowadays, Web-GIS, as well as mobile apps, are very effective and monitoring ways to attract the farmers to apply the irrigation management in their fields [74].

Khalkheili and Zamani [75] examined multiple factors (demographic, socioeconomic, and organizational) which directly affect the farmer participation in irrigation management programs and the obstacles that face the implementation of that program. Their results revealed that the farmers' participation in irrigation management is increased for the farmers with the greater land area and larger family sizes.

6 Conclusions

Agricultural activity and production sector plays a relevant role in world's food security. Approximately one-third of the world population relies on agriculture to obtain its livelihood. However, water is an important pillar and the main limiting factor on agricultural production sector especially in areas vulnerable to any environmental change such as arid and semiarid regions. It is predicted that additional water development actions will be needed in order to accommodate the demands of about two billion people in the world by 2030. On that base, the need to investigate more methods and invent proper technologies for better exploitation to water in agriculture became a must. Evidences do exist that applying precision irrigation is one of the most effective techniques that could improve crop-water productivity in the agricultural sector. This technique is mainly based on understanding the land heterogeneity and soil water content and treat similar land zones in the same way. Yet, this technique requires combining accurate and highly precise large datasets on land characteristics and water resources, among other factors.

Geo-informatics (GIS RS) are efficient tools in data collection and processing and are widely used on the international level. It proved with evidence its positive and valuable impact on agricultural irrigation water management to maximize the output of the agricultural production system. It saves time and efforts consumed applying trial-and-error method of continuous data sampling. Geo-informatics, when connected with proper decision support tools, can supply decision-makers with suitable and efficient information for more sustainable planning to the country's natural resources including water share for irrigation. This will result in better food security on both regional and international levels.

Nevertheless, the highly elevated maintenance and calibration cost of used sensors in precision irrigation is considered a serious obstacle, especially in developing countries. In addition, limited access to data availability as well as being expensive are a major dilemma that scientists are facing when attempting to use geo-informatics' tools for agricultural management.

7 Recommendation

On the research base, there are substantial efforts to use new advanced technologies such as geo-informatics in water management research area. However, it is recommended to improve and generalize the applicability of those types of research at the stakeholders' level instead of only introducing them to the scientific communities. This will require concerted efforts among different entities and communities at research, stakeholder, governmental, and decision-maker levels. Therefore, cooperation on regional and international levels for better planning to increase water productivity in the agricultural sector is a must. These plans should aim to gain more crop production in both quality and quantity with less water consumption. On that base, the following are a set of recommendations and suggestions for more sustainable benefit water exploitation in agricultural sector in Egypt.

- Both scientists and policymakers should work tightly to figure out a suitable solution to overcome the elevated cost of applying geo-informatics and precision irrigation techniques as well as lack of data availability obstacles. They should focus on producing low-cost procedures and easy access networks to facilitate the produced geo-informatics related models calibration and validation under different conditions.

- The agroecological zoning atlas in Egypt needs to be updated and integrated with general and/or specific recommendations for agricultural practices, irrigation scheduling, and disease risk management.
- Further investigation and periodical update to hydrological, soil properties, land use, and water resource maps would pave the road in adopting the application of geo-informatics in agricultural irrigation and management.
- Proper plans, management, and strategies could be of great positive impact on irrigated agricultural sector for world food security. This requires precise and accurate datasets linked to calibrated and validated decision support models to help both scientific researchers and policymakers to develop the appropriate strategies for more sustainable management to the major natural resources (land, water, crop, and climate).
- There is a need to set series of campaigns to increase farmers' awareness about safe and rational water use. These campaigns shall emphasize on the successful stories about farms and pilot areas that successfully gain good profit by practicing the newly developed techniques recommended by scientists and approved by policymakers.
- Improving the socioeconomic aspect of landowners and stakeholders needs some immediate actions that can involve but are not limited to:
  - Coin a set of laws and regulations that prohibit the unsafe use of water in irrigation as the agricultural activity is the highest consumer of freshwater.
  - Improve the irrigation and drainage network infrastructure in irrigated fields. This action can be a cooperative effort of the government, nongovernmental organizations (NGOs), and the farmers' groups.
- Proper involvement and investigation to public perception are highly recommended when planning the proposed scenarios and strategies. The environmental, economic, and social impact resulting from developing the water communication units (WCUs) in Egypt should be scientifically documented and evaluated for better future planning for public involvement in agricultural developing projects.

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Hydrological Simulation of a Rainfed Agricultural Watershed Using the Soil and Water Assessment Tool (SWAT)

El-Sayed Ewis Omran

Contents

Abstract The hydrology component of the soil and water assessment tool (SWAT) watershed model was evaluated in the El-Dabaa and El-Alamian watershed of Egypt; using the runoff measured at the outlet of the watershed. At present, prediction of stream flow simulation in data-sparse basins of the northwestern coast of Egypt is a challenging task due to the absence of reliable ground-based rainfall information, while satellite-based rainfall estimates are immensely useful to

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improve our understanding of spatio-temporal variation of rainfall, particularly for data-sparse basins. The main objective of this chapter was to test the performance and feasibility of the SWAT model and the Tropical Rainfall Measuring Mission (TRMM) for prediction of runoff in the watershed with application to a study area in the Northwestern coastal zone of Egypt.

The SWAT model requires the following data: digital elevation model (DEM), land use, soil, and daily climate data for driving the model, and runoff data for calibrating the model. All these data were collected from local organizations except DEM. All input files for the model were organized and assembled following the guidelines of ArcSWAT interface of the SWAT 2012 version. The study area was delineated into 71 sub-basins and 145 hydrological response units (HRU), which are unique combinations of land use, soil type, and slope.

The model was calibrated for the period 1979–2014 and validated in the period 1971–2000 based on the availability of coinciding climatic data. The weather generator tool of the SWAT was used to fill in the missing climatic data and enabled flow simulation in the periods with missing data. The studied basins have actual runoff (Q) ranges between 0.70 and 72.9 mm annually. The study area has runoff coefficient range between 0.9 and 52% of its rainfall. Hence, the remaining rainfall is lost by infiltration and evaporation processes. Acceptable statistical parameters were obtained after calibration processes as indicated by $R^2 = 0.91$, $E = 0.78$, and $E' = 0.61$ for calibration and $R^2 = 0.82$, $E = 0.81$, and $E' = 0.61$ for validation.

Considering the good results of SWAT in this study and comprehensiveness of the model in land surface processes representation, the model is very promising for runoff, land and water management studies and expected to give valuable information to resources managers.

Keywords Agriculture, Calibration, HRUs, Hydrology, Rainfall, Runoff, Semi-arid catchment, Soil, SWAT, TRMM, Watershed modeling

1 Introduction

In many river basins across the world, water resources managers are facing challenges due to limited data availability. Climate and land use changes add more complexity to this task [1]. This situation is more noticeable in developing countries, where in many river basins no runoff data is available [2, 3] and the existing ones are of questionable quality or at best short or incomplete. Under climate change, the major challenge, which is facing Egypt, is the need for sustainable and management of natural resources, to meet the needs of a growing population. Changes in the climate regime can influence natural processes of a watershed ecosystem [4, 5] and have long-term implications on economic and ecological processes [6]. Different authorities are given great attention for the establishment of the new settlements and land reclamation projects in the Egyptian deserts, which are among the urgent national targets to produce more food for the increasing population under water stressed conditions. At the watershed scale, various management policies have been formulated under several titles including the following [7–10]:

(a) integrated watershed management;
(b) integrated environmental management;
(c) integrated water management;
(d) adaptive management; and
(e) integrated coastal zone management.

The coastal zone of Egypt has become the major site for extensive and diverse economic activities [8]. One of the promising and strategic regions for future sustainable rainfed development is the northwestern coast of Egypt, and this, in turn, depends principally on the availability of water resources. The northwestern coastal zone of Egypt is considered a promising strip due to its mild weather easy accessibility as well as the availability of remarkable precipitation. The rainfall in the coastal zone of Egypt is usually restricted to the coast but may extend a few kilometers inland [8]. In the Northwestern coastal basins, the rainfall considers the only local water resource for irrigation and domestic purposes. The land of Northwestern coast was considered one of the main regions for land reclamation and agricultural expansion projects [11]. The coastal plain representative soil in the vicinity to El-Hammam extension canal between El-Dabaa and El-Alamain was chosen for the present study. The area has 218 wadis running from south to north, where the main stream of the wadi and its delta is mainly occupied by olive and fig trees, while, the upstream is left for rainfed crops and natural vegetation. As a strategic view, the development of the coast is necessary. In order to achieve sustainable development of the coastal zone, land use plan must be adopted. That area was incorporated in the Egyptian strategic long-term development plan 2002–2022 due to its accessibility and attaining the most promising land for agricultural expansion beyond the Nile Valley and Delta of Egypt.

Several simulation models, e.g., the soil and water assessment tool (SWAT), simulate the impact of land management practices on water, runoff, and agricultural yields in watersheds with varying soils, land use, and management conditions over time [12–14]. SWAT has been tested for a wide variety of watershed scales and environmental conditions worldwide [15–17]. SWAT model can be used for the different purpose of applications in a watershed. Adeogun et al. [18] used the SWAT model to predict water balance and water yield of a catchment area in Nigeria. It was suggested that SWAT model could be a promising tool to predict water balance and water yield in the sustainable management of water resource. Abbaspour et al. [19] applied SWAT models on Thur River basin, which is located in the north-east of Switzerland to simulate all related processes affecting water quantity, sediment, and nutrient loads in the catchment. There are excellent results for discharge and nitrate and quite satisfactory results for sediment and total phosphorous as modelled by SWAT. Tibebe and Bewket [20] also applied the SWAT model to evaluate surface runoff generation and soil erosion rates for a small watershed (Keleta Watershed) in the Awash River basin, Ethiopia. They recommended SWAT model as a useful tool for soil erosion assessment of watersheds.

Understanding and modelling hydrological processes are important for the management of water resources, for runoff analysis, and for the analysis of extreme hydrological events, such as droughts or floods. Watershed hydrology models are important in addressing the impact of various problems (e.g., runoff) related to water resources assessment and development. Quantitative hydrological models are useful tools to support the development of new water resource management policies and assess water quality issues [21]. However, a significant issue with many semi-arid zones is that meteorological and hydrological data availability (e.g., runoff) is often scarce. Unfortunately, nearly all SWAT applications addressing the effect of change were performed on scenario-based predictions. A limited number of peer-reviewed papers are available that have used dynamic change feature for setting up SWAT model at a scale of single [22] to multiple sub-watersheds [23]. SWAT has not been critically applied in Egypt for hydrological analysis. Consequently, this chapter will evaluate the model performance and its processes representation to assess its suitability for El-Dabaa and El-Alamian catchment, taking into account limited data availability and access.

The main objective of this chapter is to employ the data integration (geoinformatics and field data) to build an information system for the watershed of El-Dabaa and El-Alamian basin based on SWAT methodology in remote and data scarce area. The methodology adopted to test the hypothesis is outlined in the form of four specific objectives, which are to

1. build an information system to establish baseline characteristics for the SWAT model development and application in El-Dabaa and El-Alamian catchment;
2. compare the Tropical Rainfall Measuring Mission (TRMM) rainfall product *vs.* gauge rainfall data;
3. assess the suitability and adequacy of the *TRMM* rainfall product for simulating runoff; and
4. provide invaluable evidence for future formulation of appropriate land development policies.

This study will, therefore, identify parameters that can lead to a better understanding and to better estimate values of the parameters and thus to reduce uncertainty. In addition, these characteristics will be used to provide information on the hydrological behavior of the catchment when subjected to climatic and land management forcing input. Quantitative hydrological analysis by SWAT model is thought to be a good approach to the study area of El-Dabaa and El-Alamian. The contributions of this study are in providing quantitative information that would support stakeholders and decision makers to decide to select best practices regarding land and water resource management.

2 Background of the SWAT Model

The SWAT model is a comprehensive, semi-distributed, process physically-based model [24] to simulate continuous-time landscape processes at a catchment scale. Major model components include climate, hydrology, nutrient cycle, pesticide, plant growth, and land management. Over a long continuous period, SWAT is a watershed-scale model established to assess the effects of different land use and management practices on water quantity and water quality [14]. SWAT can be used to model changes in hydrological processes, erosion, vegetation growth, and water quality in large river basins and evaluate the effects of climate change and water resources management [21, 25, 26].

SWAT was selected for this study because of its ability to simulate land management processes in larger watersheds. Also, it includes many useful components and functions for simulating the water balance, sediment loss, runoff, climate change, crop growth, and land management practices. SWAT was developed to assist water resources managers in predicting and assessing the impact of management practices on water, sediment and agricultural yields in larger watersheds. SWAT is recognized to be effective in using readily accessible data and in studying long-term influences [24, 27]. SWAT is usually executed at the daily time-based scale, though sub-daily time step applications can also be made. SWAT requires data such as weather variables, soil properties, topography, vegetation, and land management practices occurring in the catchment. ArcSWAT [28, 29] is the GIS-based graphical input interfaces, which could be used to configure a SWAT model in a GIS environment.

Applications of SWAT typically involve delineation of a watershed into subwatersheds/subbasins that are then further subdivided into hydrologic response units (HRUs). HRUs are homogeneous areas of aggregated land use, soil, and slope and are the smallest modeling units used in the model. The incorporation of HRUs in SWAT has provided flexibility for simulating a broad spectrum of conditions and supports the adaptation of the model for watershed scales ranging from small field plots to the entire river basins [14]. Through the Arc-SWAT 2012 version, the input lup.dat file permits HRU fraction updating throughout a simulation run. The (lup.dat) file is particularly useful to initialize mid-simulation conservation measures. After its initialization, the practices continue in effect for the remnants of the simulation. Nevertheless, the (lup.dat) file is not extensively used yet due to its impractical set-up/use, therefore, any update must be made for each HRU one by one.

3 Materials and Methods

3.1 Study Area

The study area is located between El-Dabaa and El-Alamian. Geographically, studied site is bounded by Longitudes 28° 20′ and 29° 00′ Easting, and by Latitudes 30° 45′ and 30° 50′ Northing (Fig. 1). A field survey was performed for the study area in June 2013, which was guided by a global positioning system (GPS) receiver to get acquainted with different soil, elevation, and land-use and land-cover patterns. The area was reclaimed to be irrigated primarily by El-Hammam extension canal, which stretched along 57 km towards the west from El-Alamian to El-Dabaa and passes through the studied area in the vicinity to its south border.

Fig. 1 El-Dabaa and El-Alamian area

The coastal plain is a zone of variable width and elevation along the Mediterranean coast. Its width varies from few meters near headlands to some kilometers, along with enclosed gulfs. Its elevation varies from average mean sea level to about 100 m. Different phases of tectonic upheaval took place during Middle until Tertiary (Fig. 2).

The geological formation of the Western Mediterranean coast of Egypt has nine Ridges separated by eight depressions that run parallel to the present Mediterranean coast [31].

1. The coastal plain is very narrow or even lacks across headlands. Sometimes it becomes wider, with pronounced successive ridges and depressions. The surface of the plain is undulated, occupied by a series of elongated ridges parallel to the coastline. Several ridges start near Lake Mariut and gradually become less evident towards the West.
2. At a regional level, the coastal plain becomes wider eastwards (Eastwards from El-Dabaa) and becomes narrow where the headlands exist (West El-Dabaa).
3. Southwards, the coastal plain is bounded by the cliffs of the structural plateau. Sometimes, the piedmont plain reaches more than 50 m in the south. They alternate with shallow depressions, dissected by shallow dry valleys.
4. The eastern side of the headland represents the outlet of drainage lines; which are close to sea level, giving rise to salt marshes.
5. The headlands themselves are cut by sea waves (such cliffs were formed on Miocene formation [32]).

Quaternary deposits constitute the main groundwater source in the area. The winter rainfall varies seasonally with an annual mean intensity of precipitation of

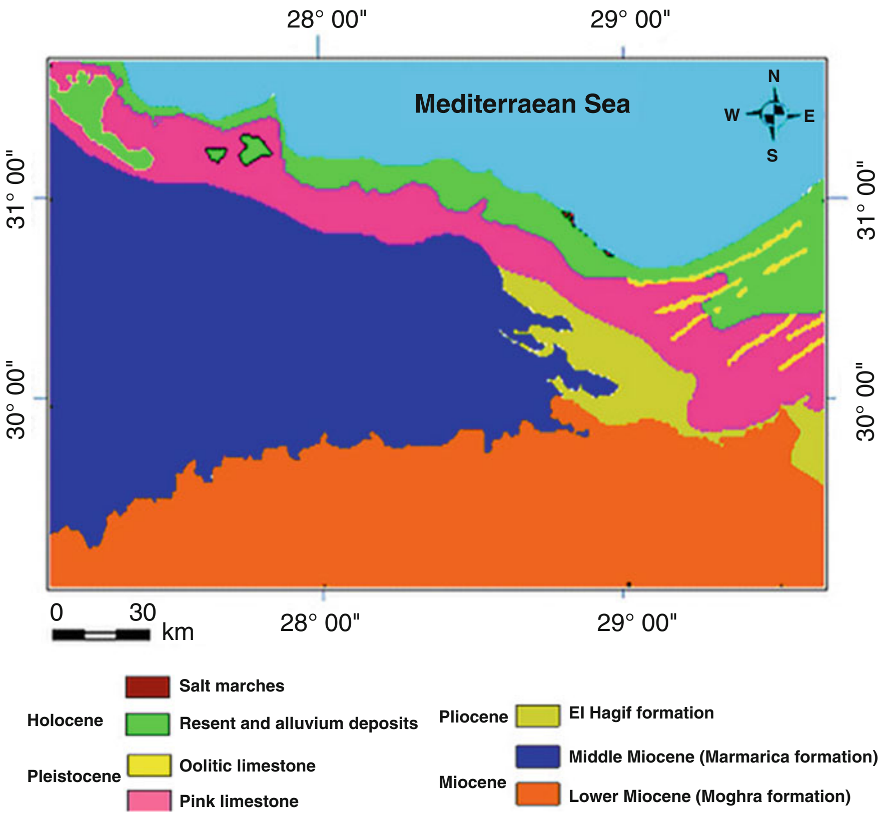

Fig. 2 Geological formation of the western Mediterranean coast of Egypt [30]

170 mm/years [33] representing the main recharging source for such formations. The maximum annual rainfall recorded was 274.6 mm during 1989 and 1990. The annual mean of rainfall is about 139.2 mm [34]. The depth of water level from the ground surface varies from 3 to 25 m. Ridges and depressions in Burg El-Arab area control the groundwater flow pattern. Groundwater flow in this aquifer is due north and northeast [35, 36]. Hydrologically, the groundwater in the area is below the free water table situation where saturated thickness of the coastal aquifer was about 30 m in Pleistocene Oolitic limestone [37]. The groundwater flow was mostly towards the Mediterranean Sea coast. The coastal aquifer mostly contained brackish water that has been recharged annually by local rainfall and the Nile seepage water from El-Nasr, El-Hammam and Mariout canals [38]. The high salinity of the ground water could be due to the long residence time in the marine Miocene sediments in El-Dabaa and the Pleistocene aquifers in El-Alamein area [30]. Nile water reached the Northwestern Coast land via four irrigation canals; El-Nubaria, El-Nasr, Bahieg and El-Hammam canals. The first stage of El-Hammam canal has been constructed along 50 km aiming to reclaim and

cultivate about 72,000 feddans in El-Hammam region. El-Hammam extension canal had been implemented along 57 km to irrigate 148,000 feddans as the second stage for the agricultural development of the area between El-Dabaa to El-Alamain.

El-Dabaa area is divided into three geomorphological units [39]: the coastal plain, piedmont plain, and tableland (Fig. 3). The coastal plain is characterized by the occurrences of sand sheets and coastal ridges, and it hosts tourist villages. Here, ground elevation varies from 7 to 50 m above sea level (amsl) and contains a series of elongated ridges that run parallel to the present shoreline. These ridges represent ancient shorelines of the Mediterranean Sea and are composed of Oolitic limestone with different degrees of hardness. The piedmont plain unit is located southward from the coastal plain and ranges from about 40 m amsl in the northern part to 75 m amsl in the south. Gentle northward slopes with a gradient of about 1 m/km are widespread. Calcareous loamy deposits cover the floor of the plain, while inland ridges are scattered in the northern and middle parts of the piedmont plain. The tableland occupies the southern part of the study area and represents the main watershed where its surface is broken by a series of transverse shallow valleys. The elevation of the tableland varies between 75 and 125 m amsl. It has northwards slopes, where development of hard crusts on its weathered surface is common. Pliocene and middle Miocene limestone deposits build the associated basement that is covered partially by accumulations of Aeolian sand dunes. In total, the tableland occupies an area of 750 km^2, and its average surface gradient is 2.25 m/km.

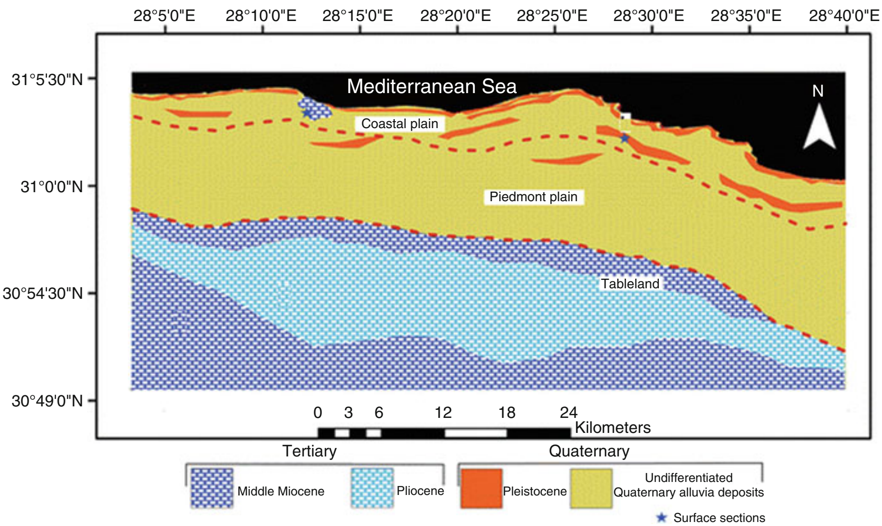

Fig. 3 The main landforms and geology of the study area (Conoco [40], and data from Landsat 8 for 2014 and SRTM-C) [39]

3.2 Overall Methodology

The SWAT model application in the current study can be divided into six steps: data preparation, sub-basin discretization, HRU definition, parameter sensitivity analysis, calibration and validation, and uncertainty analysis. The entire database required by the SWAT model has been developed for the study area, and the model has been setup for the area. The methodology, main procedure and various steps for the modelling at the basin outlet using SWAT is depicted in the flow chart (Fig. 4).

SWAT automatically delineates a watershed into sub-watershed based on a digital elevation model (DEM). DEM was imported into the model, and the mask is manually created in the model to extract out the sub-catchment area. The critical source area or the minimum drainage area required to form the origin of a stream was taken as 10,000 ha. SWAT model generated 71 sub-basins of the El-Dabaa and El-Alamian sub catchment area. The outlet is defined at the location of the monitoring station.

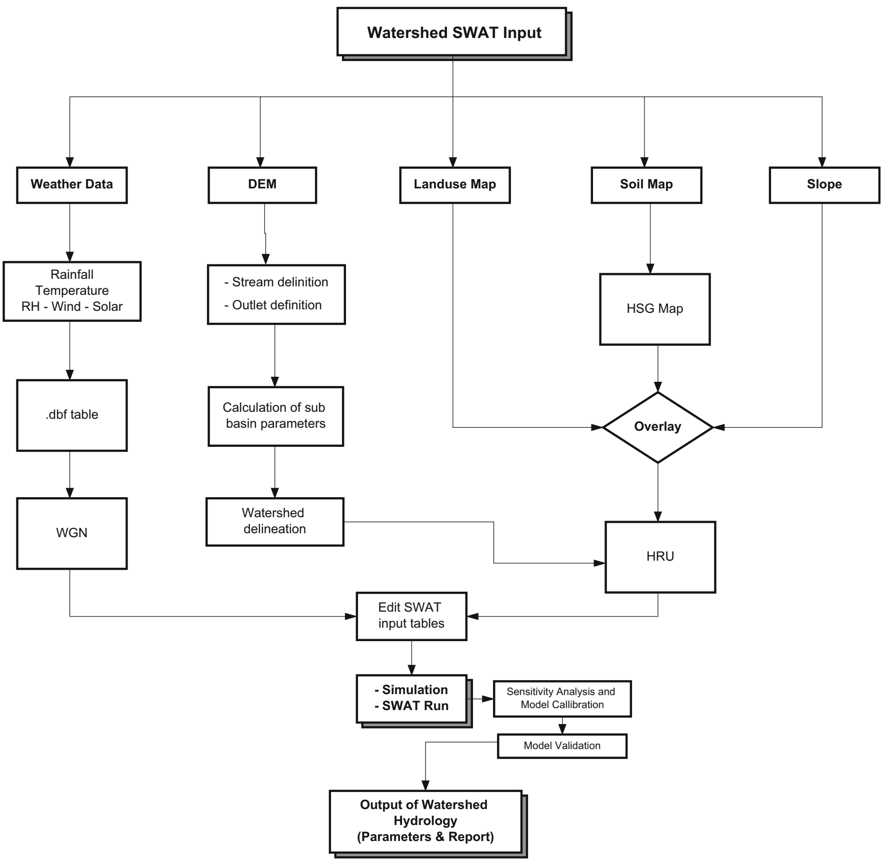

Fig. 4 SWAT model components and methodology for El-Dabaa and El-Alamian area

Watershed was delineated for the present study, and all parameters were calculated for each sub-basin. The area delineated by the model was found to be 662.63 ha. After that, reservoir locations were defined in the basin.

The SWAT model also requires many input parameters related to land use, soil, weather, topography, and runoff, which may necessity to be calibrated and validated earlier to use the model for accurate analyses. Calibration and validation of a SWAT model for a watershed are critical for decreasing uncertainties and increasing the confidence of the user for effective and efficient analysis [41, 42]. SWAT can be calibrated and validated at the daily, monthly or annual time scales depending on the purpose of the specific modeling exercise.

3.3 Database Development for the Study Area

Spatial data (DEM, soil and land use) are used in the preprocessing phase and fed into the SWAT model through the interface. The data were processed with ArcGIS interface and other appropriate techniques. SWAT model requires spatial and meteorological data in daily scale (Fig. 5).

Digital elevation model is one of the leading input of SWAT. DEM was obtained from global DEM. The SRTM DEM for the study area was obtained at 90 m resolution. DEM was used as input for automatic watershed delineation and stream generation. The DEM map for the study area organized to use with SWAT is given in Fig. 5.

Land use/land cover map is an important consideration and a critical input for the SWAT. Soil data plays an essential role in the various processes of hydrological modeling. In ArcSWAT, various soil properties like soil texture, hydraulic conductivity, bulk density, water content are essential to make an input to the model. The digitized soil map was used in SWAT, and the soil properties for different layers were fed as the input data for the soil.

Daily weather data from two stations; El-Dabaa and Borg El-Arab were available for this study. The model requires daily data for precipitation and temperature that is provided in the .dbf format and is stored in the project database. Figure 5 postulates the average meteorological data (1971–2000) from El-Dabaa in the west and Borg El-Arab in the East. The maximum temperature (30.3 and 30.0°C) is recorded in August in Borg El-Arab and El-Dabaa respectively, while the minimum (6.3 and 7.8°C) is recorded in January, respectively. The annual rate maximum temperature is 24.1 and 24.4°C in Borg El-Arab and El-Dabaa respectively. Precipitation is considered as the main source of recharge of groundwater aquifers in the northwestern Mediterranean coastal zone and affects significantly the amount of water stored in such aquifers. The Mediterranean coastal zone of Egypt receives noticeable amounts of rainfall, especially in winter. The annual rainfall is high (104 mm for Borg El-Arab and 119 mm for El-Dabaa). The maximum monthly rainfall is 33 mm in

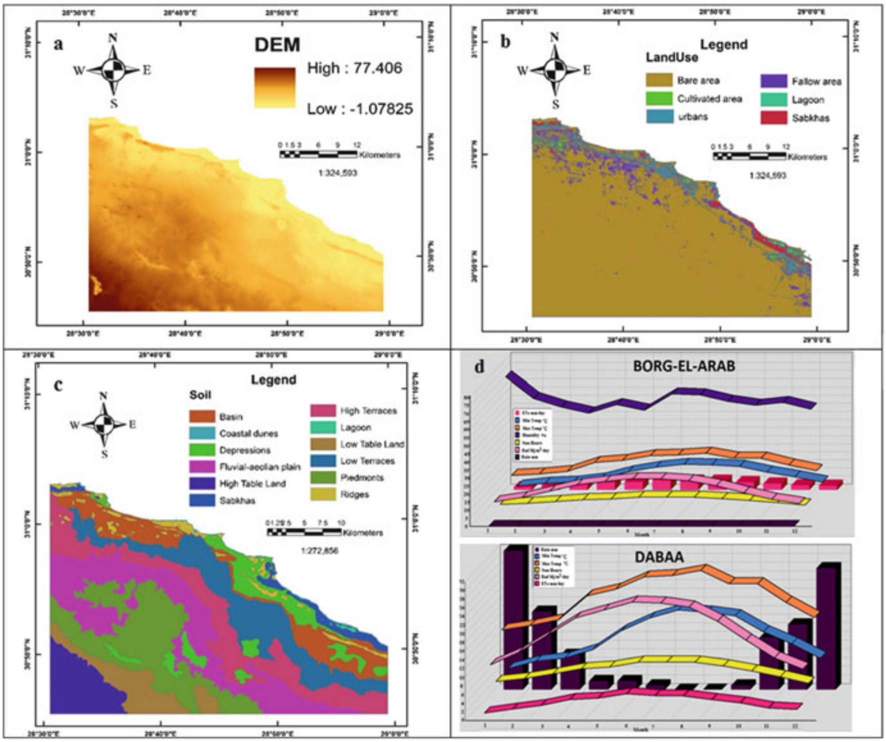

Fig. 5 Basic spatial and weather data input for the SWAT model in El-Dabaa and El-Alamian. (**a**) DEM; (**b**) Land use map; (**c**) Soil map; and (**d**) Meteorological data

January in Borg El-Arab while the maximum monthly rainfall is 32 mm in January in El-Dabaa. The relative humidity plays a vital role in the amount of evaporation and evapotranspiration. The values of relative humidity in Borg El-Arab are relatively high in summer months. The maximum values of relative humidity (Fig. 5) are recorded in July and January, being 71–81% in Borg El-Arab and 66–70% in El-Dabaa respectively. While the maximum and the minimum dominant wind at the study area is mostly directed southwest in the winter months while being northwest in summer months. Surface wind velocity varies from 233 to 320 and from 354 to 501 km/day in Borg El-Arab and El-Dabaa stations, respectively.

3.4 HRUs

HRUs are the hydrological response unit that divides the watershed into various homogeneous units based on the land use, soil type, and slope at each grid. Hydrologic response units for each sub basin were created. SWAT requires the land use and soil data to define the HRUs for each sub-basin. Land use and soil map have been imported in the model. Land use class is used to identify the land use layer. Soil look up table is used to specify the type of soil to be modeled for each category linked to the SWAT database and reclassified land use and a soil map. The soil map reclassified the database in eight hydrological soil group (HSG) based on their infiltration rate (Fig. 6). The land use map was reclassified into six different categories. The slope map is reclassified in four classes as showed in Fig. 6. The study area has been classified into six major land use classes namely cultivated area, lagoon, sabkhas, fallow area, urban, and bare area (Fig. 6).

Next, the land use, soil and slope maps were overlaid. To eliminate the minor land use, soil, and slope, threshold percentage method was adopted, and the 5% threshold for land use, 10% threshold for both soil and slope was used. Many HRUs options were chosen in the HRU definition tool. 145 HRUs were generated in the watershed. The HRUs were delineated, and the corresponding report was generated by the model, which specified the area of different HRUs in various sub-basins.

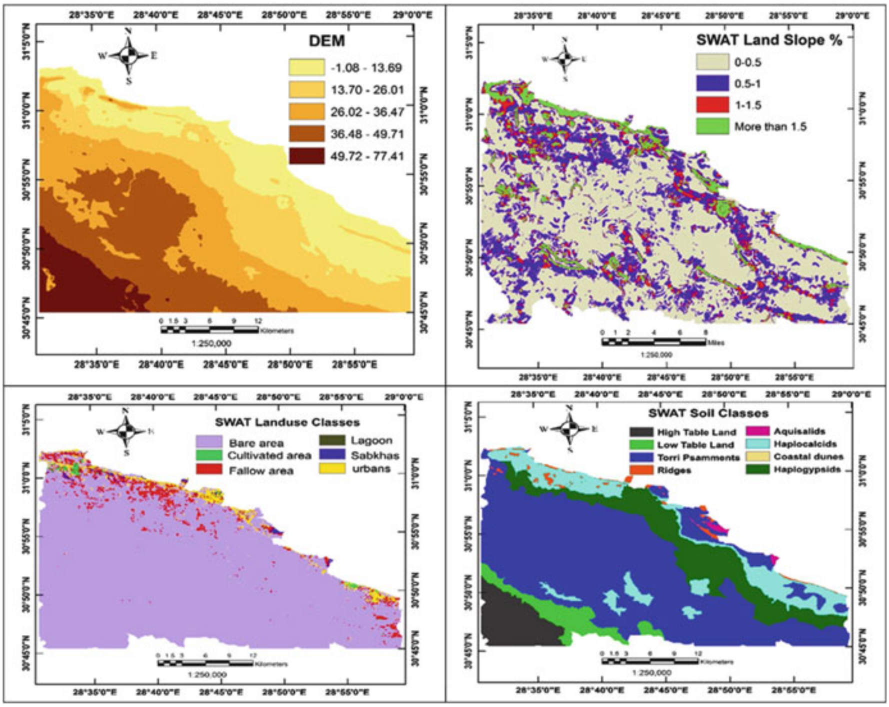

Fig. 6 HRU processed data of DEM, land slope, land use, and soil

3.5 TRMM 3B42RT Dataset

Precipitation is one of the greatest factors in the procedure of the hydrological cycle. As basic input data for hydrological model simulation, the quality of precipitation data applies a great impact upon the trustworthiness of the simulation results. At present, precipitation estimates are generally derived from two sources, i.e., rain gauge station observations and ground radar measurements. Rain gauge, though as a direct precipitation measuring instrument, which is technologically established and extensively used, cannot reflect the spatial variation of rainfall efficiently due to the distribution of rainfall stations and the very limited effective radius of point measurements [43]. In comparison with a rain gauge, the ground radar system can offer the immediate spatial distribution of precipitation over the basin indirectly and consequently aid to offset the bias of rain gauge observations partly. However, because of its problem of the limited coverage area, high costs of creating and preserving infrastructure, etc., there is no entire radar network of many regions. It still cannot meet the requirements of a study carried out on large-scale basins. These negatives of conventionally obtained rainfall data impose an outstanding drawback on the application of the scattered hydrological model. Progress in remote sensing has established the potential to estimate rainfall from space.

For example, satellite precipitation products such as the Tropical Rainfall Measuring Mission (TRMM) [44] has developed as a superior alternative or enhancement to traditional precipitation observations due to their high spatial–temporal resolution and accessibility over massive ungauged regions and therefore enhanced the application of distributed hydrological model in many fields immensely [45]. The Version-7 TRMM data were used, and this includes both the near real-time version (3B42RT) and the post real-time version (3B42). Specifically, the 3B42RT dataset is available starting March 1st, 2000, whereas the 3B42 is the latest version of the gauge-adjusted, post-real-time TRMM product, which supersedes all earlier versions [46]. The 3B42RT uses the TRMM Combined Instrument (TCI) dataset, which contains the TRMM precipitation radar (PR) and TRMM Microwave Imager (TMI), to calibrate precipitation estimates derived from the available Low Earth Orbit (LEO) Microwave (MW) radiometers [47]. The 3B42 adjusts the monthly accumulations of the 3-h fields from 3B42RT based on a monthly gauge analysis, including Global Precipitation Climatology Centre (GPCC) $1^\circ \times 1^\circ$ monthly rain gauge analysis [48], and Climate Assessment and Monitoring System (CAMS) $0.5^\circ \times 0.5^\circ$ monthly rain gauge analysis. The mean daily-accumulated TRMM 3B43 and 3B42RT data have been calculated and used as the SWAT input. TRMM visualization and analysis were used to obtain the accumulated rainfall (Fig. 7).

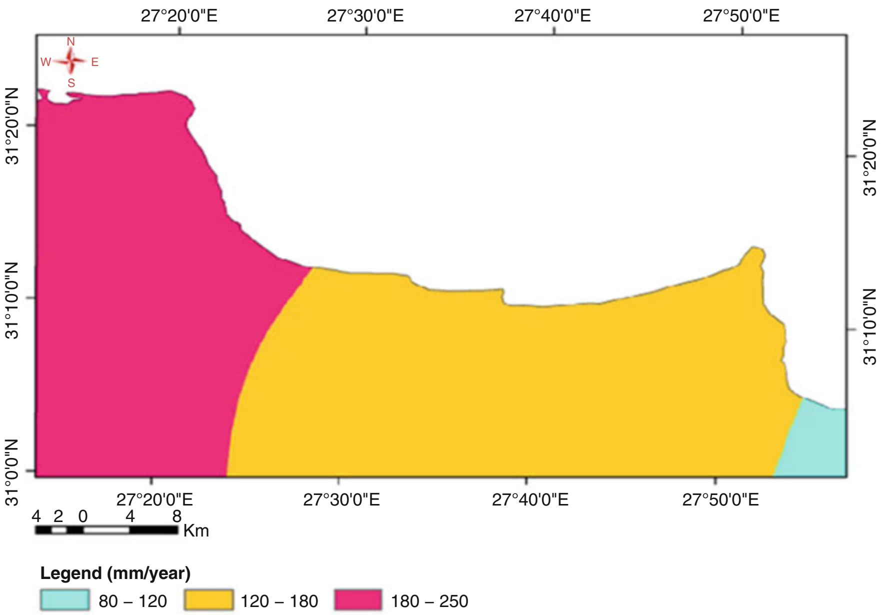

Fig. 7 TRMM average annual rainfall for the study area [49]

3.6 *Runoff Volumes*

Estimation of surface rainfall–runoff relationships is vital for any rainwater harvesting system. The current work is concerned with the amount of runoff produced from annual rainfall where this amount should be harvested. No regular daily meteorological measurements had been made within the study area, but monthly rainfall data is available. Under these circumstances, the employment of sophisticated procedures for calculating runoff was unsuitable. This problem was attempted by applying the curve number (CN) method. The CN is a hydrologic parameter used to describe the surface water runoff potential for drainage area, and it is a function of land use, soil type, and soil moisture. The current study used the curve number, which was calculated by Mahmoud [50], where it has more benefits than the tabulated curve numbers. Mahmoud [50] conducted a study to evaluate the curve number and the potential runoff coefficient using geographic information system (GIS) based on the area's hydrologic soil group, land use, land cover, and slope. He also used a global monthly precipitation data and the evapotranspiration values to estimate the rainfall surplus. Consequently, the curve number, which used in the current work is more accurate since it based on several layers, which were not used before for the study area (i.e., evapotranspiration values and rainfall surplus). The runoff volume estimation is expressed mathematically as follows:

$$Q = (P - Ia)^2/(P + 0.8\,S) \text{ for } P > 0.25 \tag{1}$$

where Q is the daily surface runoff (millimeters), P is the daily rainfall (millimeters), Ia is an initial abstraction, and S is potential maximum retention. The retention parameter, S, varies among watersheds because of soil, land use, management, and slope all vary, and with time because of changes in soil water content.

A dimensionless curve number CN is defined such as $0 < \text{CN} > 100$

$$S = (25,400/\text{CN}) - 254 \tag{2}$$

$$Q\text{v m}^3 = Q\ (\text{actual runoff m}) \times A\ \left(\text{area m}^2\right) \tag{3}$$

where Qv is the total runoff volume for an area, m^3.

From Eqs. (1) and (2), the actual runoff in the current study was estimated for each basin, and the total volume of the runoff was estimated by using Eq. (3). Finally, an evaluation of the outputs was carried out by calculating the percentages of the runoff volume to the total rainfall in the study area.

SWAT simulates surface runoff volumes and peak runoff rates for each HRU using daily or sub-daily rainfall amounts using a modification of the soil conservation service curve number (SCS-CN) method. In the curve number method, the curve number varies non-linearly with the moisture content of the soil profile, reaching its lowest value when the soil profile approaches the wilting point and increases to near 100 as the soil approaches saturation.

3.7 *Model Parameterization and Performance Evolution of the Model*

The SWAT model represents the large-scale spatial heterogeneity of the studied area by dividing the watershed into subcatchments. Each sub-catchment is parameterized using a series of hydrologic response units (HRUs) which are a particular combination of land cover, soil, and management. Soil surface runoff and sediment yield are simulated for each HRU and then aggregated for the subbasin by a weighted average. Physical characteristics, such as the slope, reach dimensions, and climatic data are considered for each sub-basin.

The model was evaluated to determine the performance that how the model, simulated value fitted with the observed value. Statistics techniques like the coefficient of determination are one of the methods to assess the model performance and also estimate that at which level simulate value fitted with the observed value. It shows the best fitness and efficiency of the model. R square describes the proportion of the total variance in the measured data that can be explained by the model. It ranges from 0.0 to 1.0. High values are indicating better agreement.

The results of the simulation were analyzed for "goodness-of-fit" with the observed data. The coefficient of determination (R^2) and coefficient of efficiency (E) was employed for model assessment. Additionally, it should be noted that R^2 and E are overly sensitive to extreme values, which may mislead the evaluation of model performance. To avoid this, a revised coefficient of efficiency was defined as E', which could reduce the effect of the squared terms. The formulas for these coefficients are listed in the following.

$$R^2 = \left\{ \sum_{i=1}^{N} (Oi - O')(Si - S') | \sqrt{\sum_{i=1}^{N} (Oi - O')^2} \sqrt{\sum_{i=1}^{N} (Si - S')^2} \right\} \tag{4}$$

The coefficient of efficiency E is given as:

$$E = 1 - \frac{\sum_{i=1}^{N} (Oi - Si)^2}{\sum_{i=1}^{N} (Oi - O')^2} \tag{5}$$

E is dimensionless and ranges from minus infinity to 1. The results are highly satisfactory for an E value equal or larger than 0.75, satisfactory between 0.36 and 0.75, and unsatisfactory for an E value smaller than 0.36.

The modified coefficient of efficiency is calculated as:

$$E' = 1 - \frac{\sum_{i=1}^{N} |Oi - Si|}{\sum_{i=1}^{N} |(Oi - O')|} \tag{6}$$

In general, E' has a lower value than E, and the model can be considered satisfactory when E' ranges from 0.51 to 0.71.

4 Results and Discussion

4.1 Watershed Delineation and Morphometric Analyses

Figure 8 represents the hydrologic cycle for this study. The hydrology module simulates major hydrologic components and their interactions as simple responses using empirical relationships (Fig. 8). Average annual values for hydrologic components, such as surface and lateral runoff, groundwater contribution to stream flow, percolation, soil water storage, evapotranspiration, and water yield, were obtained from SWAT outputs and compared to calculated values, based on precipitation and stream flow measurements. According to the SWAT model, the following main data

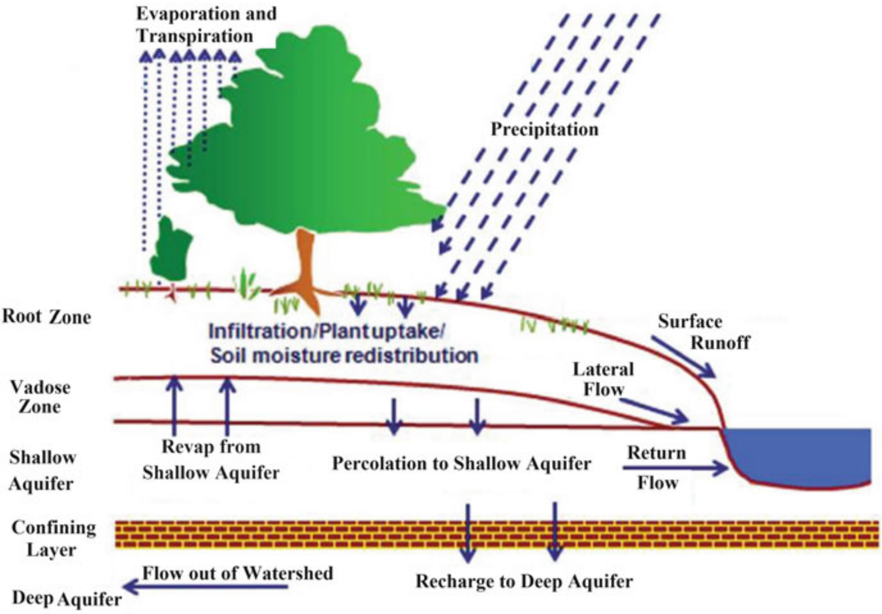

Fig. 8 Hydrological effects under the actual observed by the SWAT model and Flow direction and accumulation

were used: DEM, land use, soil and weather data. First, maps (e.g., DEM, land use and soil) were imported in Arc-SWAT. In the next step, land use and soil map were overlaid for the watershed. In addition, the weather data were defined. Finally, it was run and simulated period from 1979 to 2014.

ArcGIS and Arc SWAT software programs are used to delineate watershed and sub-watershed using a topographic map (DEM) of 90 m by 90 m ground resolution. The model set up of El-Dabaa and El-Alamian watershed is done, and the stream is defined based on drainage area threshold of 10,000 ha, which is chosen from the possible range of values proposed by SWAT. Accordingly, 71 sub-basins of El-Dabaa and El-Alamian watershed are created. The total area of El-Dabaa and El-Alamian watershed is then determined to be 703.3485 km^2. The results obtained after the model run were presented in Table 1.

The obtained results from the DEM analyses reveal that the study area contains eight basins, which have slightly intensive drainage networks (Fig. 9). The subbasins have sizes between 0.01 km^2 (basin 46) and 30.99 km^2 (basin 57).

Basins (35, 40, 41, 54, and 68) have the highest CN, annual rainfall, actual runoff, and runoff coefficients, respectively. However, the basins (59, 62, 69, 71, 56, 58, and 67) have the lowest actual runoff and runoff coefficients, respectively. Basin 69 has the lowest annual precipitation (80 mm) and high latitude, which are in line with their location and the semi-arid part of the basin. Also, the basins (67, 20, 1, 57,

Table 1 The morphometric parameters of the basins and subbasins

Sub-basin	Lat	Long	Elev (min)	Elev (max)	A (m^2)	Slo1	Len1	Sll	Csl	Wid1	Dep1
1	31.02	28.55	0	33	18,242,500	1.46	8625.42	121.91	0.26	7.37	0.42
2	30.99	28.54	11	39	11,004,200	0.66	6623.40	121.91	0.37	5.44	0.34
3	30.98	28.56	11	31	6,282,200	0.86	5233.75	121.91	0.37	3.89	0.27
4	30.95	28.56	22	38	8,265,600	0.62	6539.43	121.91	0.19	4.58	0.30
5	30.94	28.74	2	32	13,253,600	0.60	10552.01	121.91	0.28	6.08	0.37
6	30.94	28.78	2	7	113,200	0.30	1533.85	121.91	0.33	0.35	0.05
7	30.96	28.53	22	35	9,797,400	0.52	7408.14	121.91	0.16	5.07	0.32
8	30.92	28.52	30	47	10,313,500	0.30	7361.38	121.91	0.22	5.23	0.33
9	30.92	28.53	30	35	432,100	0.25	2140.95	121.91	0.21	0.78	0.09
10	30.92	28.55	30	46	8,730,700	0.63	5576.89	121.91	0.18	4.73	0.31
11	30.93	28.76	3	21	7,295,000	0.58	5471.80	121.91	0.32	4.25	0.29
12	30.91	28.78	2	27	8,413,800	0.73	6983.99	121.91	0.33	4.63	0.30
13	30.93	28.81	0	25	11,420,000	0.91	8088.74	121.91	0.08	5.56	0.34
14	30.91	28.8	2	15	557,400	0.88	2816.40	121.91	0.41	0.91	0.10
15	30.91	28.76	4	27	4,369,400	0.87	3955.46	121.91	0.54	3.12	0.23
16	30.89	28.71	15	43	9,856,200	0.36	10921.53	121.91	0.26	5.09	0.32
17	30.9	28.74	15	39	7,947,400	0.43	8959.69	121.91	0.27	4.47	0.30
18	30.91	28.71	4	43	18,461,000	0.40	14073.37	121.91	0.27	7.42	0.42
19	30.89	28.82	3	25	12,673,100	1.37	7993.35	121.91	0.23	5.92	0.36
20	30.9	28.54	28	48	15,059,900	0.71	8812.91	121.91	0.20	6.57	0.38
21	30.88	28.56	34	38	762,500	0.51	1877.88	121.91	0.20	1.10	0.12
22	30.88	28.76	2	38	27,552,700	0.40	14318.80	121.91	0.24	9.43	0.49
23	30.88	28.57	33	38	2,535,200	0.53	3437.83	121.91	0.07	2.25	0.19
24	30.88	28.61	34	49	21,397,600	0.38	9206.90	121.91	0.07	8.11	0.44
25	30.86	28.58	32	43	4,512,100	0.38	3867.47	121.91	0.18	3.19	0.24
26	30.86	28.53	33	63	16,226,900	0.50	8916.56	121.91	0.32	6.87	0.40

27	30.85	28.61	33	43	8,558,000	0.51	5846.24	121.91	0.14	4.68	0.31
28	30.87	28.81	3	23	10,352,800	0.35	9257.91	121.91	0.20	5.24	0.33
29	30.85	28.55	34	66	16,191,300	0.53	9557.92	121.91	0.33	6.86	0.40
30	30.85	28.79	18	31	9,572,700	0.34	7819.97	121.91	0.14	5.00	0.32
31	30.85	28.59	33	42	2,046,600	0.98	4985.34	121.91	0.14	1.98	0.17
32	30.86	28.72	27	44	11,949,700	0.53	10236.33	121.91	0.15	5.71	0.35
33	30.84	28.76	20	31	3,944,600	0.31	5834.21	121.91	0.18	2.94	0.23
34	30.84	28.58	33	43	1,744,800	0.78	2726.87	121.91	0.33	1.80	0.16
35	30.82	28.55	39	66	8,368,600	0.52	7377.02	121.91	0.34	4.62	0.30
36	30.85	28.69	28	44	14,796,300	0.52	6958.56	121.91	0.21	6.50	0.38
37	30.83	28.82	20	31	17,180,000	0.30	8115.30	121.91	0.13	7.11	0.41
38	30.83	28.68	28	41	2,003,700	0.78	5106.93	121.91	0.22	1.96	0.17
39	30.84	28.91	3	26	17,628,700	0.75	8864.04	121.91	0.09	7.22	0.41
40	30.84	28.66	28	43	8,808,700	0.34	6805.83	121.91	0.12	4.76	0.31
41	30.82	28.59	32	57	12,152,900	0.91	6100.62	121.91	0.38	5.77	0.35
42	30.83	28.71	28	42	3,078,400	0.69	5089.30	121.91	0.19	2.53	0.20
43	30.83	28.74	27	36	5,173,900	0.33	4196.88	121.91	0.18	3.46	0.25
44	30.82	28.68	28	43	5,383,100	0.94	4441.43	121.91	0.15	3.54	0.25
45	30.82	28.94	5	21	3,942,300	0.51	6617.29	121.91	0.06	2.94	0.23
46	30.82	28.96	7	9	8,700	0.30	990.48	121.91	0.30	0.07	0.02
47	30.81	28.72	29	42	8,216,200	0.64	5100.68	121.91	0.16	4.56	0.30
48	30.8	28.91	5	33	8,868,800	0.53	11821.10	121.91	0.22	4.78	0.31
49	30.82	28.96	6	21	2,226,500	0.50	2468.94	121.91	0.04	2.09	0.18
50	30.83	28.78	18	40	11,657,500	0.43	9251.27	121.91	0.21	5.63	0.35
51	30.8	28.78	24	33	66,500	0.48	3502.07	121.91	0.18	0.25	0.04
52	30.81	28.75	26	40	8,071,500	0.45	6606.30	121.91	0.20	4.52	0.30
53	30.8	28.78	24	30	929,000	0.45	2656.81	121.91	0.09	1.23	0.13

(continued)

Table 1 (continued)

Sub-basin	Lat	Long	Elev (min)	Elev (max)	*A* (m^2)	Slo1	Len1	Sll	Csl	Wid1	Dep1
54	30.81	28.56	39	67	11,633,100	0.51	8795.96	121.91	0.31	5.62	0.35
55	30.8	28.98	5	23	11,575,200	0.71	6967.02	121.91	0.24	5.61	0.35
56	30.8	28.96	6	23	5,724,300	0.58	5580.68	121.91	0.28	3.67	0.26
57	30.81	28.63	32	55	30,991,100	0.57	10112.59	121.91	0.19	10.12	0.51
58	30.8	28.89	5	35	9,439,100	0.51	15049.86	121.91	0.18	4.96	0.32
59	30.78	28.94	6	31	7,108,900	0.45	6438.95	121.91	0.37	4.18	0.28
60	30.79	28.75	25	45	16,053,700	0.46	7890.45	121.91	0.24	6.82	0.39
61	30.79	28.79	23	42	9,390,800	0.54	6811.21	121.91	0.21	4.95	0.32
62	30.79	28.87	12	36	10,841,600	0.63	6045.47	121.91	0.37	5.39	0.34
63	30.77	28.77	24	43	7,439,100	0.45	7837.47	121.91	0.18	4.30	0.29
64	30.79	28.7	32	50	17,903,700	0.55	8467.48	121.91	0.16	7.28	0.41
65	30.78	28.83	27	36	8,517,800	0.39	6355.00	121.91	0.13	4.66	0.31
66	30.79	28.66	32	52	15,039,700	0.35	9623.36	121.91	0.18	6.56	0.38
67	30.78	28.92	5	35	16,080,600	0.49	11389.70	121.91	0.22	6.83	0.39
68	30.77	28.81	28	42	13,874,200	0.41	7625.53	121.91	0.18	6.25	0.37
69	30.76	28.96	6	31	13,775,800	0.47	8104.58	121.91	0.21	6.22	0.37
70	30.78	28.57	33	76	25,192,800	0.44	14792.61	121.91	0.28	8.94	0.47
71	30.77	28.88	13	37	14,370,000	0.44	11615.84	121.91	0.21	6.38	0.38

Slo1 Subbasin slope %, *Len1* Longest path within the subbasin m, *Sll* Field slope length m, *Csl* Subbasin tributary reach slope m, *Wid1* Subbasin tributary reach width m, *Dep1* Subbasin tributary reach depth m

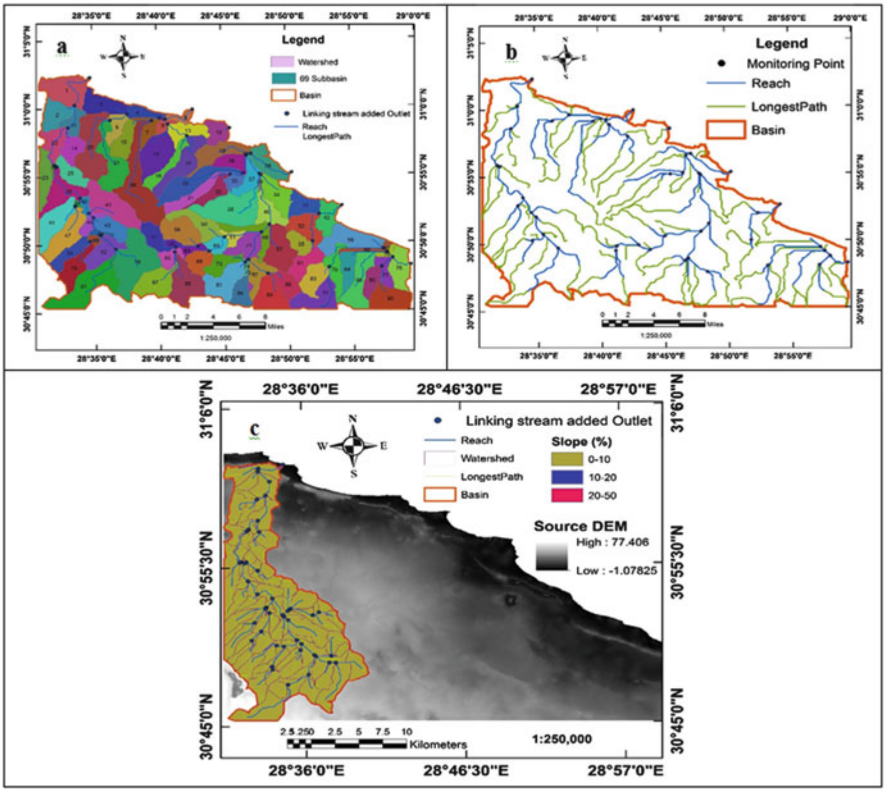

Fig. 9 Data layers extracted from the DEM analysis and used for determination of morphometric parameters by the use of ArcGIS. Watershed and basins (**a**); drainage lines, longest path, and stream orders (**b**); and slope of subbasin and DEM (**c**) of the study area

and 60) have the lowest minimum elevation (ElevMin). However, the basins (43, 58, 62, 50, and 19) have the highest ElevMax.

4.2 Surface Runoff Estimation

Figure 10 and Table 2 shows the actual runoff (Q), average rainfall (P) and runoff coefficients (C) of 71 basins. Runoff coefficients of various watersheds were estimated using rainfall and runoff data. The estimation of surface runoff (Q) is based on the curve number method. The curve number values of the study area have been extracted from the curve number map. This map was created using a combination of developed thematic layers; hydrologic soil group, slope, rainfall, evapotranspiration, and land use [50]. The obtained curve number values for the studied basins are between 75 and 42 (Table 2). The majority of the basins are covered by pixels, which

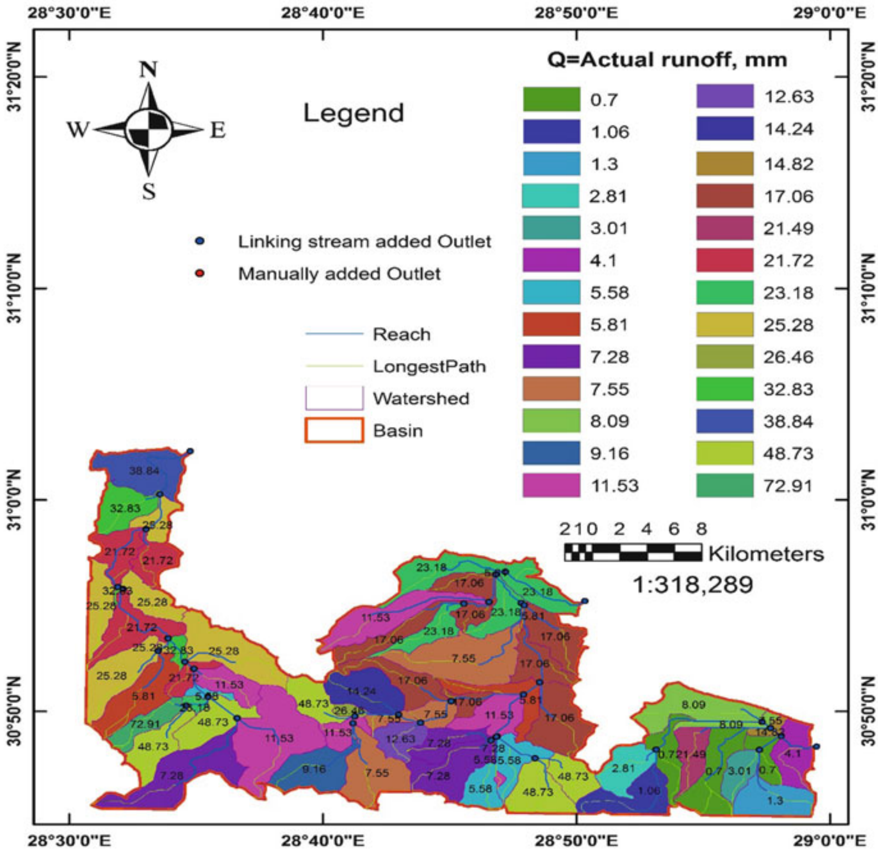

Fig. 10 Surface runoff depth

have curve number value from 44 to 50. The results (Table 2) reveal that the studied basins have actual runoff (Q) ranges between 0.70 and 72.9 mm, annually. The evaluation of all these results reflects that the study area has runoff coefficient range between 0.9 and 52% of its rainfall. Hence, the remaining rainfall is lost by infiltration and evaporation processes (Fig. 10).

Amongst the 71 different basins, the highest mean runoff coefficient (0.52) was found in basins 35. Results showed that the mean runoff coefficients for the basins 35, 40, 41, 54, 65 and 68 were higher than the other basins.

With the run-off coefficient calculation, it is likely to quickly estimate the influence of the land use change on the run-off volume. The run-off of the remaining situation can be associated with potential land use changes. The increase or decrease in impermeable surfaces will affect the amount of storm water discharge or flooding risks if the watercourses can manage the change.

Table 2 The parameters of the basins and subbasins

Sub-basin	Lat	Long	*A* (m^2)	CN	*P* (mm)	*P* (in.)	*S* (mm)	*I*a (mm)	*Q* (mm)	*Q* (in.)	*Q*/*P* (%)	C
1	31.02	28.55	18,242,500	53	160	6.3	225.25	0.27	38.84	1.53	24.28	0.24
2	30.99	28.54	11,004,200	50	160	6.3	254	0.35	32.83	1.29	20.52	0.21
3	30.98	28.56	6,282,200	46	160	6.3	298.17	0.47	25.28	1	15.8	0.16
4	30.95	28.56	8,265,600	44	160	6.3	323.27	0.53	21.72	0.85	13.57	0.14
5	30.94	28.74	13,253,600	50	140	5.51	254	0.35	23.18	0.91	16.56	0.17
6	30.94	28.78	113,200	44	111	4.37	323.27	0.53	5.81	0.23	5.24	0.05
7	30.96	28.53	9,797,400	44	160	6.3	323.27	0.53	21.72	0.85	13.57	0.14
8	30.92	28.52	10,313,500	46	160	6.3	298.17	0.47	25.28	1	15.8	0.16
9	30.92	28.53	432,100	50	160	6.3	254	0.35	32.83	1.29	20.52	0.21
10	30.92	28.55	8,730,700	46	160	6.3	298.17	0.47	25.28	1	15.8	0.16
11	30.93	28.76	7,295,000	46	140	5.51	298.17	0.47	17.06	0.67	12.19	0.12
12	30.91	28.78	8,413,800	50	140	5.51	254	0.35	23.18	0.91	16.56	0.17
13	30.93	28.81	11,420,000	50	140	5.51	254	0.35	23.18	0.91	16.56	0.17
14	30.91	28.8	557,400	44	111	4.37	323.27	0.53	5.81	0.23	5.24	0.05
15	30.91	28.76	4,369,400	46	140	5.51	298.17	0.47	17.06	0.67	12.19	0.12
16	30.89	28.71	9,856,200	46	140	5.51	298.17	0.47	17.06	0.67	12.19	0.12
17	30.9	28.74	7,947,400	50	140	5.51	254	0.35	23.18	0.91	16.56	0.17
18	30.91	28.71	18,461,000	50	111	4.37	254	0.35	11.53	0.45	10.39	0.10
19	30.89	28.82	12,673,100	46	140	5.51	298.17	0.47	17.06	0.67	12.19	0.12
20	30.9	28.54	15,059,900	44	160	6.3	323.27	0.53	21.72	0.85	13.57	0.14
21	30.88	28.56	762,500	46	160	6.3	298.17	0.47	25.28	1	15.8	0.16
22	30.88	28.76	27,552,700	46	111	4.37	298.17	0.47	7.55	0.3	6.8	0.07
23	30.88	28.57	2,535,200	50	160	6.3	254	0.35	32.83	1.29	20.52	0.21
24	30.88	28.61	21,397,600	46	160	6.3	298.17	0.47	25.28	1	15.8	0.16
25	30.86	28.58	4,512,100	44	160	6.3	323.27	0.53	21.72	0.85	13.57	0.14

(continued)

Table 2 (continued)

Sub-basin	Lat	Long	A (m^2)	CN	P (mm)	P (in.)	S (mm)	Ia (mm)	Q (mm)	Q (in.)	Q/P (%)	C
26	30.86	28.53	16,226,900	46	160	6.3	298.17	0.47	25.28	1	15.8	0.16
27	30.85	28.61	8,558,000	50	111	4.37	254	0.35	11.53	0.45	10.39	0.10
28	30.87	28.81	10,352,800	46	140	5.51	298.17	0.47	17.06	0.67	12.19	0.12
29	30.85	28.55	16,191,300	44	111	4.37	323.27	0.53	5.81	0.23	5.24	0.05
30	30.85	28.79	9,572,700	44	111	4.37	323.27	0.53	5.81	0.23	5.24	0.05
31	30.85	28.59	2,046,600	44	110	4.33	323.27	0.53	5.58	0.22	5.07	0.05
32	30.86	28.72	11,949,700	46	140	5.51	298.17	0.47	17.06	0.67	12.19	0.12
33	30.84	28.76	3,944,600	46	140	5.51	298.17	0.47	17.06	0.67	12.19	0.12
34	30.84	28.58	1,744,800	50	140	5.51	254	0.35	23.18	0.91	16.56	0.17
35	30.82	28.55	8,368,600	75	140	5.51	84.67	0.35	72.91	2.87	52.08	0.52
36	30.85	28.69	14,796,300	44	140	5.51	323.27	0.53	14.24	0.56	10.17	0.10
37	30.83	28.82	17,180,000	46	140	5.51	298.17	0.47	17.06	0.67	12.19	0.12
38	30.83	28.68	2,003,700	52	140	5.51	234.46	0.3	26.46	1.04	18.9	0.19
39	30.84	28.91	17,628,700	44	120	4.72	323.27	0.53	8.09	0.32	6.74	0.07
40	30.84	28.66	8,808,700	75	110	4.33	84.67	0.53	48.73	1.92	44.3	0.44
41	30.82	28.59	12,152,900	75	110	4.33	84.67	0.35	48.73	1.92	44.3	0.44
42	30.83	28.71	3,078,400	46	111	4.37	298.17	0.47	7.55	0.3	6.8	0.07
43	30.83	28.74	5,173,900	46	111	4.37	298.17	0.47	7.55	0.3	6.8	0.07
44	30.82	28.68	5,383,100	50	111	4.37	254	0.35	11.53	0.45	10.39	0.10
45	30.82	28.94	3,942,300	44	120	4.72	323.27	0.53	8.09	0.32	6.74	0.07
46	30.82	28.96	8,700	46	111	4.37	298.17	0.47	7.55	0.3	6.8	0.07
47	30.81	28.72	8,216,200	51	111	4.37	244.04	0.33	12.63	0.5	11.38	0.11
48	30.8	28.91	8,868,800	55	120	4.72	207.82	0.22	21.49	0.85	17.91	0.18
49	30.82	28.96	2,226,500	50	120	4.72	254	0.35	14.82	0.58	12.35	0.12
50	30.83	28.78	11,657,500	50	111	4.37	254	0.35	11.53	0.45	10.39	0.10

51	30.8	28.78	66,500	44	110	4.33	323.27	0.53	5.58	0.22	5.07	0.05
52	30.81	28.75	8,071,500	46	110	4.33	298.17	0.47	7.28	0.29	6.62	0.07
53	30.8	28.78	929,000	46	110	4.33	298.17	0.47	7.28	0.29	6.62	0.07
54	30.81	28.56	11,633,100	75	110	4.33	84.67	0.2	48.73	1.92	44.3	0.44
55	30.8	28.98	11,575,200	52	80	3.15	234.46	0.3	4.1	0.16	5.12	0.05
56	30.8	28.96	5,724,300	44	80	3.15	323.27	0.53	0.7	0.03	0.87	0.01
57	30.81	28.63	30,991,100	50	111	4.37	254	0.35	11.53	0.45	10.39	0.10
58	30.8	28.89	9,439,100	44	80	3.15	323.27	0.53	0.7	0.03	0.87	0.01
59	30.78	28.94	7,108,900	50	80	3.15	254	0.35	3.01	0.12	3.76	0.04
60	30.79	28.75	16,053,700	46	110	4.33	298.17	0.47	7.28	0.29	6.62	0.07
61	30.79	28.79	9,390,800	44	110	4.33	323.27	0.53	5.58	0.22	5.07	0.05
62	30.79	28.87	10,841,600	46	90	3.54	298.17	0.47	2.81	0.11	3.12	0.03
63	30.77	28.77	7,439,100	44	110	4.33	323.27	0.53	5.58	0.22	5.07	0.05
64	30.79	28.7	17,903,700	46	111	4.37	298.17	0.47	7.55	0.3	6.8	0.07
65	30.78	28.83	8,517,800	75	110	4.33	84.67	0.35	48.73	1.92	44.3	0.44
66	30.79	28.66	15,039,700	55	90	3.54	207.82	0.22	9.16	0.36	10.17	0.10
67	30.78	28.92	16,080,600	44	80	3.15	323.27	0.53	0.7	0.03	0.87	0.01
68	30.77	28.81	13,874,200	75	110	4.33	84.67	0.6	48.73	1.92	44.3	0.44
69	30.76	28.96	13,775,800	46	80	3.15	298.17	0.47	1.3	0.05	1.63	0.02
70	30.78	28.57	25,192,800	46	110	4.33	298.17	0.47	7.28	0.29	6.62	0.07
71	30.77	28.88	14,370,000	42	90	3.54	350.76	0.6	1.06	0.04	1.18	0.01

CN Curve number, *P* Average annual of total rainfall, *A* Area, *S* Potential maximum retention, *I*a Intial abstraction, *Q* Actual runoff, % *Q*/*P* % Actual runoff *Q* to total rainfall *P*, *C* Rrunoff coefficients

4.3 Effect of Land Use, Soil, and Slope Thresholds

Analysis of HRU definition showed that main type of HRU definition resulted in a single HRU for each subbasin where the dominant land use, soil, and slope within the area was considered to be the land use, soil, and slope of each subbasin. This single HRU within each subbasin was not able to adequately represent the features of the subbasins.

The model needs daily data for precipitation and temperature that is delivered by the user in the .dbf format and is kept in the project database. Remaining required climatic data can be created as the user specified .wgn file. Accordingly, the simulated runoff shows the disappointing result as compared to the measured runoff in the eight basins of the study area. The multiple scenarios that account for 10% land use, 20% soil and 10% slope threshold combination gives a better estimation of runoff in the Basin. It resulted in 145 HRUs in the entire basin. This scenario resulted in detailed land use, slope and soil database, containing many HRU, which in turn represent the heterogeneity of the study area.

4.4 SWAT Simulation

Hydrologic modeling of El-Dabaa and El-Alamian watershed was carried out using the ArcSWAT. After preparing data files and completing all model inputs, the model is ready for simulation. The simulation is done for the same period of availability of climate data. The hydrology simulation by SWAT is based on different parameters that have to be calibrated and adjusted. In such case, the calibration process becomes complex and computationally extensive. Hence, parameter reduction by filtering out the less influential ones was essential before calibration. The sensitivity analysis is so used to identify and rank the most responsive hydrological parameters that have a significant impact on specific model output, which is the outflow in this case. The sensitivity analysis was made using a built-in SWAT sensitivity analysis tool that uses the Latin Hypercube One-factor-At-a-Time (LH-OAT) [51]. The model is simulated many times by changing the input calculation method and the value of hydrological parameters that ranked by the model to get the best match between model output and observed flow data.

4.5 Impact of Subbasin Discretization and Model Performance

The model was generated runoff series for the study area from 1979–2014 in-depth units (mm). The performance of the model in terms of simulated runoff was evaluated using the statistical method and compared simulated runoff with the observed values to a significant extent. The coefficient of determination (R^2) for the runoff values was observed for the runoff. The results are shown in Table 3. The relationship shown in Table 3 provides an indication of how the satellite image derived rainfall amounts fit the gauge-measured rainfall. A suggestion that the absence of reliable ground measurements of rainfall product can adequately be applied to estimate the spatial rainfall distribution based on the value of $R^2 = 0.91$ as achieved by linear modeling.

The model efficiency was computed using the default simulation result and the measured data. It was observed that the threshold area resulted in 71 subbasins that accounts for the key drainage lines inside the watershed. This resulted in an enhanced representation of the hydrological processes and produced runoff, which had a better model efficiency in comparison to the measured runoff. A number of subbasins above this threshold have brought no significant changes in the simulation of runoff. The overall results showed that the simulation of runoff is not significantly affected by increasing the size of the threshold area. The results have shown that subbasin discretization on SWAT model has limited impact on runoff prediction in the study area. On the one hand, this is mainly because prediction of surface runoff is highly related to curve number. On the other hand, the curve number is not affected significantly by the size of the subbasin.

Before calibration, E and E' both had negative values. These parameters indicated that substantial differences existed between simulations and observations. However, acceptable statistical parameters were obtained after calibration processes. As shown in Table 3, at an annual scale, the difference between simulated and observed average annual runoff was minimum as indicated with statistical parameters included $R^2 = 0.91$, $E = 0.78$, and $E' = 0.61$ for calibration and $R^2 = 0.82$, $E = 0.81$, and $E' = 0.61$ for validation.

At the monthly scale, statistical analyses showed that $R^2 = 0.81$, $E = 0.53$, $E' = 0.35$ for calibration and $R^2 = 0.80$, $E = 0.60$, and $E' = 0.37$ for validation. Monthly scale simulation was barely satisfactory. Some months were overestimated, whereas some were underestimated. The main reason for this is that the monthly runoff data were calculated from the measured data when sampling in the middle of each month. This process may lead to a large difference for the actual flow, especially in the rainy or dry periods, and it may yield a smaller or larger result when estimating the monthly runoff based on this value. These results confirm the ability of the model to predict runoff after calibration.

Table 3 Estimated statistical parameters of model performance for calibration and validation

	Calibration			Validation		
	R^2	E	E'	R^2	E	E'
Annual scale						
Run off	0.91	0.78	0.61	0.82	0.81	0.61
Monthly scale						
Run off	0.81	0.53	0.35	0.80	0.60	0.37

5 Conclusions

The setup and evaluation of a complex physics-based model SWAT in the data-poor environment of the El-Dabaa and El-Alamian catchment, Egypt are discussed in this chapter. For this study, a SWAT model was set up, using a coarse spatial dataset, point rainfall data, a dominant HRU combination and other physical information about the basin. It is imperative to note that in the model set-up, attention should be on the classification of land use and soil type to match the SWAT's classification and type respectively.

Results of the current study confirmed a good SWAT model performance to predict runoff at subcatchment levels with adequate prediction uncertainty. During model set-up, it was found that the land use classification (especially the vegetation types) was a sensitive issue for the runoff estimation. Overall, for simulated and measured runoff volumes on an average basis, the statistical results were better in the calibration period than in the validation period. SWAT model provides a useful tool for soil runoff assessment from watersheds and facilitates planning for sustainable land management.

In a context where rain-fed agriculture remains the most threatened economic sector by climate change and is mainly subsistence-oriented, irrigation has become an alternative solution in Egypt frequently facing hydro-meteorological droughts. SWAT has the advantage that it can accommodate to changes in time, climate, and environment. Because of that, it can be used for water resources forecast and impact studies, by updating input data. This information will help in the assessment of existing and future hydrological impacts of climate and land use changes, and the improvement of suitable approaches of adaptation to climate change.

However, it is worth noting that the major limitations that arose within this study are mainly limited climate data availability (rain gauge density, time series length). Consequently, this study, to the knowledge of the author, is the first to successfully demonstrate the utility of satellite-estimated precipitation (TRMM 3B43 and 3B42RT) in supporting hydrologic modeling with SWAT in Egypt. Therefore, it is advised potentially extending the realm (between 50N and 50S) where remotely sensed precipitation data can support hydrologic modeling outside of regions that have modern, ground-based radar networks (i.e., much of the third world).

6 Perspectives and Recommendations

Data constitutes the backbone of any water resources management. Therefore, to improve model accuracy and reduce prediction uncertainties, additional data have to be used. This suggests that:

- In a future study, it is recommended to use subbasin model set-up, more distributed HRU combinations and to avoid the use of the weather simulator for model validation. Satellite derived rainfall data may, therefore, be useful. Also, more consideration should be given to the physical basis of the parameters in forthcoming research.

- We need to identify the hydro-meteorological measuring network to collect information at the maximum amount of points possible. Moreover, more, not only data quantity is required, but also data of good quality, which is measured following, accepted guidelines and are easily traceable to their sources to facilitate quality control procedures.
- Exploiting new measurement technologies such as remote sensing can help keep pace with the evolving water issues.

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Part VI
Conclusions

Update, Conclusions, and Recommendations for Sustainability of the Agricultural Environment in Egypt: The Soil–Water–Food Nexus

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Abstract This chapter casts light on the main conclusions and recommendations of the chapters presented in this volume. In addition, it discusses some findings from a few recently published research works related to the soil–water–food nexus. Therefore, this chapter contains information on water scarcity in Egypt, soil toxicology, heavy metal contamination, sustainable agriculture, geostatistics and proximal soil sensing in agricultural management, the role of intercropping systems in sustainable crop production, rice production, bioactive compounds in soybeans, and plant biotechnology. In addition, a set of recommendations for future research work is provided to direct future research toward sustainability, which is the main subject of strategic importance under Egyptian circumstances.

Keywords Contamination, Geostatistics, Intercropping, Plant biotechnology, Proximal sensing, Soil toxicology, Sustainability, SWAT model, Water deficiency

1 Introduction

The future of agriculture in Egypt faces many challenges. Among the most important of these are water deficit, environmental pollution, and food shortages. The proposed solutions are improvement of agricultural procedures and use of modern technologies such as visible near-infrared and shortwave infrared, reflectance spectroscopy, geostatistics, and remote sensing (RS). Modern techniques play an essential role in the diagnosis of soil, plant, and water status, and accurately identify water and nutrition needs. Developments in irrigation systems and crop varieties with more drought tolerance, as well as intercropping systems, represent essential strategies for decision makers and have played a significant role in increasing productivity. Next to all of these developments, biotechnology offers a better way to enhance crop productivity and therefore reduce the gap between food production and consumption. Addressing toxicity of water and land with the impact of environmental pollutants and heavy metals is another challenge for Egypt's decision makers to ensure food safety. Therefore, achievement of agricultural sustainability requires close cooperation between the government, nongovernmental organizations, and farmers' groups. This chapter presents general conclusions on sustainable agriculture and its importance for Egypt and researchers. In designing sustainable agricultural production systems, it is necessary to give due consideration to the various resources used and the soil–water–plant nexus, which render the current production system unsustainable. So, the intention of this volume is to address, assess, and propose improvement measures on the following main themes:

– Sustainable agriculture in Egypt.
– Potential applications for increased crop productivity.
– Biotechnology applications for agricultural sustainability.
– Potential of soil sensing for sustainable agriculture.

The next section presents a brief on the important findings of some recently updated and published studies on sustainable agriculture, followed by the main conclusions of the chapters in this volume, in addition to the authors' main recommendations for researchers and decision makers. The update, conclusions, and recommendations presented in this chapter come from the data presented in this volume.

2 Update

The following sections provide the major update for this volume, classified on the basis of the major themes.

2.1 Sustainable Agriculture in Egypt

The soil–water–food nexus faces several challenges in the provision of food security. Among the most important of these are water deficit, soil toxicity, and environmental pollutants. Three approaches have been identified to increase sustainable food supply in Egypt.

The first approach as a strategy to adapt to water scarcity is deficit irrigation management. Increasing competition for water resources among the agricultural sector, domestic consumption sector (such as municipalities), and industrial sector requires new irrigation strategies to allow water saving and maintain efficient levels of production in semiarid regions [1]. A national strategy was instituted for reusing agricultural drainage water for irrigation purposes in the 1970s. For example, in the El-Salam Canal in the eastern part of the Nile Delta, Nile water is mixed with agricultural drainage water in a ratio of 1:1 [2]. The total water withdrawal between 2010 and 2015 was 68.3 km^3/year, distributed among the agricultural, municipal, and industrial sectors. The agricultural sector is considered the main consumer, as it is the core of the Egyptian economy. The agricultural sector consumes approximately 59 km^3/year for irrigation purposes and other agricultural activities. With double cropping (production of two crops per year), intensive agriculture has doubled the water demand. Also, the loss of water by evapotranspiration from cultivated lands is estimated to be 3 km^3/year [3].

The second approach is an increase in water productivity in Egyptian agriculture. It is important to employ geographic information in water management on farms in order to improve crop production in the cropping system in Egypt. Surface irrigation, as a traditional irrigation method, is responsible for loss of a significant proportion of the water, which may reach up to 60% or more if it is not managed properly. Reducing the losses of applied irrigation water should lead to an increase in water productivity. Improvement in water productivity can be achieved in several ways such as replacement of plant varieties with improved high-yielding ones, optimization of production inputs such as fertigation, improved agricultural practices, and improved irrigation methods [4]. Also, irrigation system modernization accompanied by better coordination between managers, users, and stakeholders should be considered to improve water productivity [5].

The third potential approach identified to increase the sustainable food supply is soil toxicology. Soil toxicity is one of the factors negatively affecting the productivity and quality of agricultural products. There are now numerous essential national and global endeavors in progress to create, enhance, and institutionalize strategies for evaluating soil quality, especially for use in managing the potential perils of both soils and the contaminant materials they may contain [6, 7]. Bioavailability can be defined as the physicochemical effect that a toxicant has on the natural processes of a living being [8]. The less bioavailable toxicant is the less harmful impact it has on a living being. Allen [8] concluded that various physical and substance variables, including soil pH, natural matter, and synthetic types of components in the earth (i.e., carbonate as well as sulfate) influence the potential for metal ionization and accessibility.

2.2 Potential Applications for Increased Crop Productivity

Three potential approaches have been identified for using natural products to increase sustainable agriculture in Egypt.

The first potential approach concerns the role of intercropping in maintaining and facilitating environmental sustainability. From the crop science perspective, intercropping not only has positive effects on maintenance of soil water and utilization of available environmental resources but also facilitates the activity of microorganisms and nitrogen fixation. Therefore, this leads to improvements in the physiological and biochemical characteristics of the plant rhizosphere, reflected positively in increased productivity. In addition to the beneficial effects of intercropping in encouraging the proliferation of natural enemies, reduces disease and insect injury and inhibiting weed growth undoubtedly lead to an increase in the final production of the intercropping unit area under sustainable agriculture [9]. Multiple benefits can be obtained from application of different intercropping systems that improve soil conditions and the environment in which the plant grow, and thus increase crop productivity.

The second potential approach concerns the role of intercropping in increasing sustainable crop production and reducing the food gap in Egypt. In the farming of cereals such as maize and wheat, yields and soil fertility have been improved by incorporation of pulses into intercropping. For example, intercropping of maize and soybean is considered one of the most important agricultural systems increasing the productivity of Egyptian farms, without any additional cost, because of the morphological and physiological differences between the two crops, which obtain mutual benefits [10]. Intercropping of a legume with maize is one of the best production systems and least risky techniques [11].

Sustainable cultivation of rice in Egypt is the third approach being used to address the food availability challenge in Egypt to cope with its fast-growing population in a restricted area of land. Rice productivity in Egypt has increased remarkably year after year, according to the percentage replanting of rice cultivation areas with modern varieties to realize a maximum yield average of 10 t ha^{-1} in the 2014 season, versus 5.7 t ha^{-1} in the period 1986–1998. Rice is a semiaquatic plant and very sensitive to water deficit [12, 13]. The main constraint on rice cultivation in Egypt is the limited source of irrigation water from the Nile River and the shortage of available water, especially in terminal canals in the North Delta, where rice cultivation is concentrated. Also, rice consumes large quantities of water during its growing season, which could be directed toward reclamation of new land and planting of more crops. Thereby, production of new short-duration and water stress–tolerant rice cultivars could save about 30% of the irrigation water consumption every year [14].

2.3 Biotechnology Applications for Agricultural Sustainability

Various approaches have been identified for using biological control as a potential tool in sustainable agriculture.

The first approach involves bioactive compounds in soybean proteins. From the perspective of health benefits, soybean proteins are characterized by the presence of biologically active compounds, especially isolated and refined proteins, e.g., glycinin, basic subunit and β-conglycinin, which has provided antibacterial activity against pathogenic and spoilage bacteria [15, 16]. Another approach to obtain new antibacterial proteins is tailored chemical modifications of native proteins. According to Sitohy et al. [17], "esterification can neutralize the negatively charged carboxyl groups of the aspartyl and glutamyl residues on protein molecules, transforming their net charge into positive. The obtained positively charged proteins were proved antimicrobially active" [17], and they were shown to inhibit the growth of *Listeria monocytogenes* and *Salmonella enteritidis* in raw milk [18, 19]. Furthermore, research has been done to find out the effectiveness of *Moringa* seeds in improving water quality and purifying wastewater.

A report by Hendrawati et al. [21] stated that "the common methods of water purification using synthetic materials such as aluminum sulfate (alum) and calcium hypochlorite are not efficient, because these materials are imported and thus ... the water cost becomes relatively expensive in most economically developed countries and is not affordable for most rural population. Therefore, some people try to get water source from dams, mining, small streams, rivers, and lakes. Water from these sources is usually turbid and contaminated with microorganisms that may cause various diseases" (http://iopscience.iop.org/article/10.1088/1755-1315/31/1/012033/pdf) and [20, 21]. Several findings from previous research have demonstrated that use of synthetic materials for water purification can be severely hazardous to health if something goes wrong in their treatment during processing. Besides synthetic chemicals, there are natural ingredients, derived from tropical plants, that can be used as coagulants, including *Moringa oleifera* seeds. *Moringa* seed extract (MSE) has shown promise as a natural flocculant and biocoagulant, which aids in binding solids in turbid water [22] and improves the physicochemical properties of contaminated water. Previous research has found that *Moringa* is not toxic, and it is recommended for use as a coagulant in developing countries.

Over 7,000 known plant species are domesticated, suggesting that a significant share of potential food sources is underutilized. Recent agricultural developments have focused on staples (wheat, maize, and rice) on which most of the world's population is already dependent for food security [23]. For these reasons, many edible plant species are nowadays considered minor, underutilized, or neglected, and they have joined the category of underutilized plant species (UPSs) [23]. Although no standard definition of UPSs exists, studies have described the features of UPSs and the overriding issues affecting the conservation and use of their genetic resources [23]. In Egypt, cultivation of new drought-resistant plant species that are suitable for arid and hyperarid conditions is a great challenge.

Biotechnology is an important tool in the scientific research system to improve economic characteristics, provided that food safety is maintained. However, conventional breeding is a very tedious and expensive process and takes several generations to achieve the desired results. Biotechnology is the most rapidly used technology in the history of agriculture and continues to expand in the world. In Egypt, the human population is approximately 95 million with an annual increase of 2.4% [24]. Egypt imports about 40% of its total food needs. Biotechnology offers a better way to enhance crop productivity and therefore reduce the gap between food production and consumption [25]. Egypt is one of the first African countries to consider plant biotechnology as a strategically significant tool for improving national food security and raising agricultural productivity. It started an ambitious program of plant biotechnology in 1990, aiming to resolve its agricultural constraints. Egyptian scientists, especially those at the Agricultural Genetic Engineering Research Institute (AGERI), took on the burden of solving Egypt's main agricultural problems through biotechnology. They have worked hard during the last 25 years to improve crop characteristics and have been successful in producing several genetically modified crops such as cotton, wheat, strawberry, potato, squash, melon, and tomato. These crops are in the pipeline for commercialization, pending approval by the relevant Egyptian decision makers.

Fermentation technology provides a means of sustainable biopreservation to improve the safety of food, with several important advantages. Food can be preserved through production of inhibitory metabolites such as organic acids (lactic acid, formic acid, acetic acid, and propionic acid), ethanol, bacteriocins, etc., often in combination with a decrease in water activity (by drying or addition of salt). Also, food safety can be improved through inhibition of pathogens or removal of toxic compounds, improving the nutritional value and quality of the food. Recently, the use of fermented foods has been rising (they constitute 60% of the diet in industrialized nations) and, to guarantee the homogeneity, quality, and security of food products, they are manufactured by intentional utilization of different microorganisms cultures in raw foods [26].

2.4 Potential of Soil Sensing for Sustainable Agriculture

Geostatistics is part of the wide-reaching field of spatial statistics, offering powerful tools for geospatial analysis. Most often, geostatistical techniques are used to interpolate estimates at locations where measurements have not been or could not be taken. As well as interpolation, geostatistics provides a way of understanding spatial structure and can support the process of designing sample surveys. Potentially, proximal or ground-based (invasive or noninvasive) soil sensors can collect high-resolution data rapidly and, in certain cases, even allow real-time analysis and processing by taking measurements as frequently as once per second [27].

Sustainable agriculture is increasingly viewed as a long-term goal in the quest to overcome the problems and constraints that confront economic viability, environmental soundness, and social acceptance of agricultural production systems. There is general agreement that sustainable development includes environmental, economic, and social dimensions [28]. Sustainability indicators characterizing these three dimensions are generally used to bridge the gaps between theoretical concepts and actual measures [29]. Despite the diversity in conceptualization of sustainable agriculture, there is a consensus on three basic features of it: (1) maintenance of environmental quality, (2) stable plant and animal productivity, and (3) social acceptability.

Modern sensing technologies provide a means of diagnosing the state of soil, air, and plants, so that appropriate decisions can be made regarding processes of reclamation and cultivation to increase agricultural production. Technological advancement must be utilized to provide farmers with rapid soil analysis to make farming more sustainable. Modern sensing technologies in agriculture have been given an essential role in the improvement of agricultural production to maintain food security. Soil reflectance spectroscopy is a well-known tool used to assess soil properties quickly and quantitatively [30]. Reflectance spectroscopy is less costly and quicker than traditional wet chemical measurements [31]. Visible near-infrared and shortwave infrared (VNIR–SWIR) reflectance spectroscopy is a promising technique for productive identification and monitoring of soil properties in the spectral range of 350–2,500 nm [32]. However, the relevant information for prediction of soil characteristics needs to be mathematically extracted from the spectra so it can be linked to soil attributes. For more information on this topic, the interested reader should consult the chapter titled "Rapid Soil Analysis Using Modern Sensing Technology: Towards a More Sustainable Agriculture", Part II of the book.

One of the promising and strategic regions for future sustainable development is the northwestern coastal zone of Egypt, and this in turn depends principally on the availability of water resources. This zone is considered a promising strip because of its mild weather and easy accessibility, as well as the availability of remarkable precipitation. The rainfall in the coastal zone of Egypt is usually restricted to the coast but can extend a few kilometers inland. The northwestern coast of Egypt, which is part of the Mediterranean agroecological zone, has been considered one of the most important regions for land reclamation and agricultural expansion development projects [33]. The coastal plain includes soils in the vicinity of the El-Hammam Canal between El-Dabaa and El-Alamein, which are promising areas for rain-fed agriculture. This area has been incorporated into the Egyptian strategic long-term development plan for 2002–2022 because of its accessibility and because it offers the most promising lands for agricultural expansion beyond the Nile Valley and Delta in Egypt. Several simulation models have been developed to examine and evaluate surface runoff and the soil erosion rate in the watershed, which impact different land use practices. One of these models, the soil and water assessment tool (SWAT), simulates the impact of land management practices on water, sediment, and agricultural yields in watersheds with varying soils, land use, and management conditions over time [34, 35]. Unfortunately, nearly all SWAT applications addressing the effects of land use changes have been performed on scenario-based predictions. SWAT has not been critically applied in Egypt for hydrological analysis. Consequently, the performance of the model has been evaluated with representation of its processes to assess its suitability for the El-Dabaa and El-Alamein catchment, taking into account limited data availability and access. Data integration (from geoinformatics and field data) has been employed to build an information system for the watershed of El-Dabaa and the El-Alamein basin, based on SWAT methodology in remote and data-scarce areas, to achieve the following objectives: (1) to evaluate the impacts of land use changes on runoff and sediment yield, (2) to establish baseline characteristics for SWAT model development and application in the El-Dabaa and El-Alamein catchment, and (3) to provide invaluable evidence for future formulation of appropriate government land development policies. Results confirmed a good SWAT model performance to predict runoff at subcatchment levels with adequate prediction uncertainty.

3 Conclusions

Throughout the current volume, the editorial teams have been able to reach several conclusions drawn from the data presented in the volume. Besides methodological insights, this chapter describes key lessons from the cases in the volume – in particular, the promising characteristics of both the historical and current local food systems. These conclusions are important to increase the sustainable food supply in Egypt. They are discussed in the following sections in no particular order.

3.1 Egyptian Sustainable Agriculture

Most of the Middle East and North Africa (MENA) countries are located in arid regions and suffer from heat stress and low rainfall. With the continuous increase in the Egyptian population, the limitation of conventional water resources in arable lands are considered the principal cause of water scarcity. Therefore, use of nonconventional water resources such as treated industrial and wastewater drainage, agricultural drainage water, and desalinated water is the main approach being explored to increase water resources. In addition, use of green water can be optimized by enhancing soil water conservation scenarios through conservation tillage methods, increases in soil organic matter, covering of soil surfaces with plant residues, and application of modern irrigation systems. The El-Salam Canal is the main accepted source of irrigation water with Food and Agriculture Organization of the United Nations (FAO)–permissible levels of salinity. Research results have revealed that soil salinity can be decreased by use of the normal water irrigation supply for 47.6% of the water, saving 50% of the supplied water, with higher water use efficiency of 2.36 kg/m^3.

Sustainable agriculture can be achieved under Egyptian environmental conditions. To achieve sustainability, it is important to ask where we start and what we want to achieve. Sustainable agriculture is accessible with use of small areas and poor resources. Sustainable agriculture is not associated with a particular situation, but it is important to focus on how to achieve its terms, strategies, policies, and mechanisms for its implementation. A sustainable agricultural system is similar to the Egyptian model in terms of its diversity, complexity, and weakness of resources.

Sustainable land management (SLM) combines technologies, policies, and activities aimed at integrating socioeconomic principles with environmental concerns to simultaneously satisfy the five pillars of SLM: to protect the potential of natural resources and prevent degradation of soil and water quality (protection), to reduce the level of production risk (security), to be economically viable (viability), to maintain production services (productivity), and to be acceptable (acceptability).

Some metals may be more harmful than others at low levels and less poisonous at high levels. Sessile life-forms, which cannot move away from changes in the earth, might be more tolerant than other life-forms. Estimation of poisonous properties can be done over time and with recurrent introduction, based on the physical type and concoction of the toxin. Rice straw application has been observed to be successful in immobilizing Cu and Pb in defiled soil, which substantially decreases the bioaccessibility of metals. Biochar can possibly diminish the leachability and bioavailability of substantial metals in defiled soil. There are natural aggregates that form chelates with different metal particles with a certain level of selectivity. In this procedure, the metal particle loses its ionic character and generally its poisonous quality too.

3.2 Potential Applications for Increased Crop Productivity

Under sustainable agriculture in Egypt, research results have shown that intercropping leads to an increment in land use efficiency and availability of resources (i.e., water, light, and nutrients). Also, intercropping is a successful method for avoiding pests, encouraging natural enemies of pests, and suppressing weed growth. Therefore, it achieves a yield advantage in the unit area and reduces the risks involved in crop production.

Egypt suffers from a shortage in the production of grain and oil crops, which is widening the gap between production and consumption. The productivity of these crops could increase through use of new varieties, expansion in the cultivation of new land, use of modern farming methods, and intercropping. Nitrogen fixation by legumes helps to improve soil properties and improves associated crops of cereals; thus, it could reduce the addition of manufactured fertilizers that have a polluting effect on soil. Feeding animals (e.g., sheep) on a mixture of basal hay and cowpea or lablab, yielded by a cowpea and lablab/maize intercropping system, has led to greater sheep growth performance and higher net profits. Cultivation of grain and legume crops in an intercropping system with cotton, sugarcane, and sugar beet helps to increase the productivity of the unit area and improve the production of these crops.

In Egypt, rice is considered a very important food crop. Rice cultivation has achieved a significant increase in productivity. The national research program has developed and released many cultivars of rice, characterized by high yield and early maturity. This has led to a rise in the national rice production rate from 5.6 to 9.5 t ha^{-1} in the past 30 years. Most of these cultivars are resistant to blast disease and tolerant of drought, salinity, and heat stress. It is important to maintain rice cultivation in Egypt to meet growing food needs, provide food security, and support the economy.

3.3 Biotechnology Applications for Agricultural Sustainability

Methylated products have been shown to be active against pathogenic and spoilage bacteria. Soybean protein isolate and its native fractions can be transferred into positively charged proteins by esterification with methanol in the presence of hydrochloric acid (at a 50-molar ratio). In addition, glycinin and a subunit of it have been found to be active against bacteria because of their original cationic and hydrophobic nature, and soybean β-conglycinin has been found to be active against fungi as a result of its glycoprotein structure. Hereby, supplementation of raw milk with esterified soybean protein (0.5%) has proved beneficial since it counteracted spoilage bacteria, maintaining the titratable acidity and pH at normal levels for a longer storage period (8 days instead of 4 days in cold storage). Addition of glycinin and its basic subunit to pasteurized milk can protect it from contamination with inoculated bacteria, reducing the bacterial load by about 2.5–3 logs after 16–20 days of storage at 4°C.

The seeds of *M. oleifera* are environmentally friendly because they do not harm the environment. The potential of MSE for water treatment has been demonstrated, achieving excellent results in treatment of wastewater because of its widespread availability and maximum effluent removal from both domestic and synthetic wastewater. The results showed that treatment of water with MSE gave the lowest values for water turbidity and heavy metals in comparison with untreated water. Soil irrigated with water from different sources after treatment with MSE showed a significant decrease in accumulation of Pb, Cd, Ni, Fe, Cu, Zn, and Mn in comparison with soil irrigated with water from the same sources but not treated with MSE.

Agriculture in Egypt is a major economic sector and the main reason behind most of Egypt's wealth. Agriculture is an important issue as a national food source and for international trade, the balance of payments, and land and water use. Agriculture also provides basic raw materials for industry. Egypt needs to conduct extensive research in the field of sustainable agriculture to expand food production because it has very limited arable land and water resources. Such research in Egypt requires changes in the traditional approach to problem solving.

Biotechnology plays a significant role in resolving some of the challenges and constraints faced by the agricultural sector in Egypt. Egypt started an ambition program of biotechnology in the early 1990s. Now, Egypt has well-established facilities and capacities for biotechnology. In addition, Egypt has experts in the field of genetic engineering and production of transgenic crops, especially at AGERI. Additionally, many genetically modified plants have been produced by AGERI scientists, and permission for their commercial release is now awaited.

On the basis of a survey of popular fermented dairy products in Egyptian conditions, it can be stated that use of fermented milk, such as milk converted into cheese or dairy products, provides humans with essential amino acids, vitamins, and minerals. The use of mish cheeses as appetizers makes them an important part of the diet of a large sector of the Egyptian population. The safety of these fermented foods in developing countries is vital, as these foods are an essential source of protein and other essential nutrients for humans.

Wider utilization of underutilized plant species (UPSs) in agricultural systems is a good solution to this problem. Many UPSs are rich in bioactive compounds, vitamins, antioxidants, oils, and proteins. UPSs could play an important role in the enhancement of nutrition, health, and income for local Egyptian communities. Also, UPSs are resilient in natural and agricultural conditions, making them a suitable surrogate for the major edible plants. UPSs have a promising nutritional value, but their role in nutrition security is not fully understood, and they have not yet been mainstreamed in Egyptian policies and programs for agriculture, food security, and nutrition. Optimization of these resources will improve the nutrition security of Egypt and have positive impacts on biodiversity and the Egyptian economy.

Findings from previous research have demonstrated that use of synthetic materials for water purification can be severely hazardous to health if something goes wrong in their treatment during processing. Besides synthetic chemicals, there are natural ingredients, derived from tropical plants, that can be used as coagulants, including the seeds of *M. oleifera*. Use of natural ingredients from local indigenous plants to clear muddy water is not a new idea [35].

Moringa seeds have been shown to improve water quality and remove heavy metals from water, plants, and soil under study. This preliminary laboratory result confirmed the great potential of MSE in wastewater treatment applications.

3.4 Potentiality of Soil Sensing for Sustainable Agriculture

Four approaches have been identified, which reflect the role of soil sensing in sustainable agriculture. The first approach is a combination of proximal soil sensing and geostatistical techniques to assess spatial variability of soil properties not only at large scales but also at the microscale (within-field scale). Visible and near-infrared spectroscopy are considered the primary soil sensing methods, providing detailed information about soil characteristics. Spectroscopy is easy to use, relatively inexpensive, and fast. Geostrategic tools are important because they allow for more accurate assessment of spatial variations in soil characteristics. Geostatistical tools are important as they allow more accurate assessment of spatial variations in soil properties.

The second approach is sustainable land management (SLM). Sustainable agriculture is a long-term goal in the quest to overcome problems and constraints in economic viability, environmental soundness, and social acceptance of agricultural systems in Egypt. There is general agreement that sustainable development includes environmental, economic, and social dimensions. SLM combines several technologies, policies, and activities aimed at integrating socioeconomic principles and environmental concerns. The pillars of SLM are used to protect the potential of natural resources and prevent degradation of soil and water quality to reduce risks in production.

The third tool is geoinformatics, which involves geographic information system (GIS) and remote sensing (RS). Water is an important pillar of SLM and a main limiting factor in the agricultural production sector, especially in arid and semiarid regions. To accommodate the demands of the world's population, which will increase from 6.8 billion to 8.3 billion by 2030, better methods and invention of appropriate technologies for better exploitation of water in agriculture are necessary. Geoinformatics is an efficient tool for data collection and processing, and there is evidence of its positive and valuable impacts on agricultural irrigation water management to maximize the output of the agricultural production system. It saves time and effort that would otherwise be consumed in trials and minimization of experimental error. Application of geoinformatics, when associated with the right decision, can supply decision makers with suitable and efficient information for sustainable planning of natural resources to optimize use of water for irrigation purposes and ensure food security at regional and international levels.

The fourth approach is prediction of key soil properties by use of spectroscopy. Agricultural sustainability requires adoption of modern technologies without harmful effects on the environment, to improve food productivity. Reflectance spectra provide much information and identify variations related to key soil parameters. With utilization of visible near-infrared and shortwave infrared (VNIR–SWIR) spectroscopy, good predictions of some chemical and physical properties can be achieved. This approach allows assessment of primary properties with direct spectral responses. Thus, it is possible to detect clay content, salinity, and organic matter with high accuracy. The visible band is important for organic matter estimation using spectroscopy. VNIR–SWIR spectroscopy is a promising method for fast prediction of key soil properties. For more information on this topic, the interested reader should consult the chapter titled “Rapid Soil Analysis Using Modern Sensing Technology: Towards a More Sustainable Agriculture”, Part II of the book.

Several simulation models – e.g., the soil and water assessment tool (SWAT) – simulate the impact of land management practices on water, sediment, and agricultural yields in watersheds with varying soils, land use, and management conditions over time. SWAT has been tested in the watershed of El-Dabaa and El-Alamein. The SWAT model can be used for different applications in a watershed. The study area was delineated into different subcatchments and hydrological response units (HRUs), which are unique combinations of the land use, soil type, and slope. The model was calibrated for the period 1979–2014 and validated in the period 1971–2000 on the basis of the availability of coinciding climatic data. Considering the good results of SWAT in this study and the comprehensiveness of the model in land surface process representation, the model is very promising for land and water management studies and is expected to provide valuable information for land and water resource managers. The SWAT model could be a promising tool to predict the water balance, soil runoff, and water yield for sustainable management of water resources.

4 Recommendations

Throughout this volume, the editors have noted some areas that could be explored for further improvement. On the basis of the authors’ findings and conclusions, this section offers a set of recommendations and suggestions for future research beyond the scope of this volume.

The following recommendations are mainly obtained from the chapters presented in this volume:

1. The effects of some problems in Egyptian soils, such as drought and salinity, which Egyptian stakeholders have faced in recent decades, can be treated and reduced with an acceptable level of productivity. Deficit irrigation is highly recommended for overcoming severe yield reductions and securing low yield levels. Use of green water can be optimized by improving soil water conservation scenarios with use of suitable tillage methods and organic matter, covering of soil surfaces with plant residues, and application of modern irrigation systems (sprinklers and drips, etc.)
2. Sustainable agriculture will be achieved in Egypt by understanding that it is achievable, dealing with sustainability as an integrated system, and finding solutions to the challenges of the Egyptian agricultural sector one by one. Farmers should be involved in the research system by providing information, performing analyses, introducing solutions, and implementation. In addition, involvement of external institutions and application of resource-conserving technologies should be integrated with local groups and institutions as a condition for sustainable agriculture, and all of the actors should work together in the agricultural system.

3. There is a need to examine the impact of biochar on various dangerous metals under dirty field conditions. The aim of treatment for metal poisoning is expulsion of the exposed metal from the body through use of chelation. Fruitful treatment for intoxication by substantial metals includes creation of a moderately stable chelate–metal complex in the body, which is transported in due course to the kidney and excreted. The overwhelming mineral stability of rice straw should be put to use in exceptionally polluted soils in controlled fields. The effects of chelating specialists such as ethylene diamine tetra acetic acid (EDTA) on the toxic quality and diffusion of large metals in humans and other creatures should be examined.
4. It is important to choose suitable intercropping patterns to achieve facilitative and complementary use of environmental resources (i.e., space, light, and nutrients), with selection of the best-adapted crop cultivars to maximize nutrient use efficiency and reduce nitrate leaching. In addition, growth of promising genotypes in intercropping patterns should reduce the risk of pests and increase productivity and quality to overcome the food gap between production and consumption in Egypt.
5. Intercropping should be used as one of the farming methods to increase grain and oil crop production to reduce the gap between production and consumption. The application of intercropping systems that include grain and legume crops – such as intercropping of maize with common bean, soybean, or groundnut (as oil legume crops) and also with cowpea and/or lablab (as forage legume crops) – should be extended. These approaches should lead to optimization of land use efficiency in the cultivation of cotton, sugarcane, and sugar beet, which are long-duration crops. This can be achieved through intercropping of grain crops such as wheat, legumes such as faba bean, and vegetable crops such as potatoes and onions, particularly since these cropping systems largely succeed under Egyptian conditions of soil and weather.
6. In the future, high priority should be given to developing high-yielding, biotic and abiotic stress–tolerant rice cultivars to cover requirements for local consumption and exportation. Considerable attention should be paid to sustaining rice cultivation in Egypt. It is imperative to transfer newly developed technologies to farmers to achieve maximum grain yield with minimum production costs. Also, researchers should pay attention to developing new ways to utilize crop residues such as straw in agricultural and industrial applications, to limit its environmental damage.
7. Native and modified soybean fractions could be a potential area of research to control undesirable bacteria and fungi in food and improve its safety. The soybean protein fraction of β-conglycinin can be used as an effective and environmentally friendly fungicidal agent against postharvest infections with the pathogenic fungus *Penicillium digitatum*, either in vitro or in situ (postharvest orange fruit). More studies are needed to further extract more natural bioactive protein compounds from other legumes and other types of plants.

8. Egypt is rich in biodiversity, and *Moringa* trees can grow well there, which are easy to find, and are easy to cultivate in various regions. It is recommended that the use of *Moringa* seeds in purification of wastewater be applied on a large scale and in large stations for water purification and water recycling in Egypt.
9. For further development of the Egyptian food system, the following items and steps are suggested as a strategic future framework for integration of underutilized plant species (UPSs). Cultivation of UPSs relies on less fertilizer and pesticide than cultivation of conventional crops, and consumption of UPSs can reduce health risks from chemicals in the diet. UPSs have the potential to improve farmers' incomes and overall food and nutrition security by offering diverse food production at affordable prices with fewer risks. Integration of UPSs into national food systems will reduce the climatic and economic risks associated with cultivation of advanced cereals and commercial crops. Funding of research and breeding programs for UPSs should focus on understanding their genetic diversity, determining the relationship between genotypes and phenotypes, and developing a consensus linkage map with several molecular markers. Application of molecular breeding approaches will aid UPS improvement programs. Awareness about the nutritional value of UPSs should be raised and linked to school feeding programs and support for local food chains to help establish a national industry. Contributions through research and investment from international organizations, coupled with the existing Egyptian programs, present a promising future for use of UPSs and are likely to generate interest in the private sector.
10. The Egyptian government should take serious steps to exploit the benefits of genetically modified organisms and consider changes in policy regarding their commercial release. These steps include increasing the research budget in this field, updating laboratory and research facilities, releasing a final functioning biosafety law, encouraging national and international collaboration, supporting Egyptian scientists and funding their international training, and enhancing public awareness of biotechnology issues.
11. Respect for local and global standards and production processes is one of the basic principles of food processing. The safety of products such as cheeses made from raw milk depends on the capacity of protechnological starter/protective culture components to inhibit pathogenic microbes, which can spread hazardous traits in the microbial community. More efforts are required to evaluate and implement the use of bacteriocinogenic bacteria or natural bioactive macromolecules such as peptides or extracts from herbs in those products and study their effects on the protechnological microbiota.
12. Sustainable agriculture requires knowledge of all relevant information about the soil–plant system. This cannot be achieved by traditional methods based on averages of laboratory-measured data only, so it is recommended to use proximal soil sensors that can provide fine-scale information about soil and plant parameters easily. Proximal soil sensing data can be complemented with laboratory-measured data through geostatistics to better recognize soil spatial variability. Geostatistics allows prediction of soil properties in unsampled

locations and consequent delineation of site-specific management zones, which can be used for variable rate applications.

13. To achieve sustainable agriculture, there are key features of sustainable agriculture in Egypt that can contribute to the 2030 Egyptian sustainability plan: maintenance of environmental quality, stable plant and animal productivity, and social acceptability. Addressing biophysical, socioeconomic, and environmental concerns will enhance the potentiality for sustainable agriculture. Sustainable land management (SLM) is a good strategy for development to overcome loss of soil productivity from excessive erosion, intensive cultivation, and associated plant nutrient loss; surface and groundwater pollution; impending shortages of nonrenewable resources; and low farm incomes due to low commodity prices and high production costs.
14. For more sustainable use of water in the agricultural sector in Egypt, a set of recommendations and suggestions must be taken into account. First, both scientists and policy makers should work together closely to figure out a suitable solution to overcome the high costs of applying geoinformatics and precision irrigation techniques, as well as obstacles to data availability. They should focus on devising low-cost procedures and easy-access networks to facilitate calibration and validation of the produced geoinformatics-related models. The agro-ecological zoning atlas in Egypt needs to be updated and integrated with general and/or specific recommendations for various agricultural practices, irrigation scheduling, and disease risk management. Further periodical updates to hydrological, soil property, land use, and water resource maps would pave the road to apply the geoinformatics in agricultural irrigation and management. Furthermore, there is a need for a series of campaigns to increase farmers' awareness about safe and rational water use. A new set of laws and regulations should be issued that prohibit unsafe use of water in irrigation, as the agricultural sector is the largest consumer of freshwater. The irrigation and drainage network infrastructure in irrigated fields should be improved. Also, cooperation between the government, nongovernmental organizations, and farmers' groups is essential.
15. The availability of hyperspectral cameras has provided exciting new possibilities for online defect detection. In addition, spectral imaging technologies, which acquire single or multiple images at selected wavelengths, could be used to detect specific quality attributes (pigments, sugar, starch, water, protein, etc.) in a wide range of crops and horticultural products. Application of near-infrared (NIR) spectroscopy on agricultural harvesters has shown the potential to reduce the labor and expenditure required for determination of relevant properties in different crops. Application of NIR spectroscopy in field crops is helpful for monitoring and analyzing fresh plant materials (e.g., leaves, whole plants, and other materials) without the need for traditional processing. Spectroscopic and imaging techniques should be explored for detection of symptomatic and asymptomatic plant diseases.
16. It is recommended to use a soil and water assessment tool (SWAT) model to set up more distributed hydrological response unit (HRU) combinations and avoid

use of weather simulators for model validation. Satellite-derived rainfall data may therefore be useful. Also, more consideration should be given to the physical basis of SWAT parameters in future research. We need to identify the hydro-meteorological measuring network to collect information at the maximum amount of points possible. Exploiting new measurement technologies such as remote sensing can help keep pace with the evolving water issues.

17. There is a consensus on several basic features of sustainable agriculture in Egypt that could contribute to the 2030 Egyptian sustainability plan: maintenance of environmental quality, stable plant and animal productivity, and social acceptability. In addition, SLM in agriculture is very complex and challenging from the point of view of addressing biophysical, socioeconomic, and environmental concerns to enhance the potentiality of land for sustainable agriculture. SLM is a good strategy to sustain development to overcome the loss of soil productivity from excessive erosion/intensive cultivation and associated plant nutrient loss/depletion, surface and groundwater pollution, impending shortages of nonrenewable resources, and low farm incomes due to low commodity prices and high production costs.

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