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Contents

Leaf-Cutting Ants, Biology and Control

Isabelle Boulogne, Harry Ozier-Lafontaine, and Gladys Loranger-Merciris

Abstract Leaf-cutting ants (*Formicidae*, *Myrmicinae*, *Attini*) are found on the American continent and in the Caribbean and are known to live in symbiosis with a fungus. Among *Attini* tribe, *Atta* and *Acromyrmex* are the two genera, which commonly depend on fresh plant leaves and other plant material for their fungal garden. Overall, these ants are among the most economically damaging herbivorous species. *A. octospinosus* is classified among the most serious pests of tropical and subtropical America. Due to its foraging activity, it can cause serious damages from 20 to 30 % of crop production. Huge losses were observed in several vegetable and fruit crops, in crop of cacao or citrus orchards and in protected areas where some species may completely disappear due to their endemism. Economic losses due to these ants were estimated at several million dollars per year. Although *Acromyrmex octospinosus* is one of the most important species of leaf-cutters because of its economic impact there is a lack of review in the literature.

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We review here the distribution, biology and different kind of control used and sustainable methods that can possibly help to manage. *A. octospinosus* is found only in Neotropics from Central America to northern of South America, including parts of West Indies. A colony is divided into males, breeding females, or gyne, and three castes of workers: small workers or 'minor', medium worker or 'media' and large workers or 'major'. Pheromones are indispensable supports of social life of *A. octospinosus*. Foraging is conditioned by trail pheromone and takes place along a 'line' involving all castes of the colony. The foraging is divided in several steps. Indeed, the ants cut the plant material, transport it into the nest, lick it, cut it into smaller pieces, chew it, depose fecal fluid on it, cultivate mycelium fragment on this prepared mixture and incorporate it into the symbiotic fungus. Symbiotic fungus, or 'fungus garden', is a Basidomycete, *Leucocoprinus gongylophorus* (Heim) Moeller. It is the exclusive nutrition of both juvenile stages and the queen and is also a supplement of the adult workers diet. The ant also lives with an actinomycete, *Pseudonocardia* sp. This symbiont grows on the cuticle of all ants of the colony and protects fungus garden against fungal competitors and ants against ubiquist entomopathogenic bacteria and fungi.

The first techniques used to fight against *A. octospinosus* were mechanical methods which have only local efficiency and do not prevent from the reestablishment of colonies. Synthetic chemical control against *A. octospinosus* began in the twentieth century with a direct chemical control and afterward with toxic baits. The efficiency of these controls was limited but all of them caused severe injuries on environment and human health. This situation has prompted an increasing interest in alternative methods to control this pest. Laboratory and field tests of biological control were performed with spores of pathogenous fungus or ants predators into nest, with fungal symbiont's extract and trail pheromone, with entomopathogenic fungus and nematodes. Most of these methods did not give the desired effect or were not confirmed *in situ*. Biopesticides using insecticidal and fungicidal plants are known to be environmentally safe because of their non-phytotoxicity, biodegradability and renewability. Thus, another alternative to chemical control of *A. octospinosus* has been explored with the insecticidal or fungicidal activities of plants extracts, which showed various effects on both *A. octospinosus* workers and *Leucocoprinus gongylophorus in vitro* cultures. These tests showed very encouraging *in vitro* preliminary results and may serve as alternatives to synthetic compounds to develop safer control agents of leaf-cutting ants.

Complex relationships and tripartite mutualism are involved between ants, fungus and actinomycete. All studies investigated only one side management. A tripartite management based on a combination of the three strategies should promote a more efficient integrated control and provide some interesting options for the control of this pest.

Keywords *Acromyrmex octospinosus* • Tripartite mutualism • Tripartite management • *Pseudonocardia* sp • *Leucocoprinus gongylophorus* • Sustainable pest management • Biopesticides

1 Introduction

Leaf-cutting ants are insects of the Family of *Formicidae*, Sub-family of *Myrmicinae* and Tribe of *Attini* that includes 12 genera and approximately 200 species (Weber 1972). They are found on the American continent and in the Caribbean (Fig. 1). The *Attini* are known to live in symbiosis with a fungus. These features are the reason why they are called fungus-growing ants. Among the *Attini* tribe, *Atta* and *Acromyrmex* are the two genera which commonly depend on fresh plant leaves and other plant material for their fungal garden. This is the reason why they are also commonly called leaf-cutting ants (Wetterer et al. 1998). Overall, these ants are among the most economically damaging species causing huge losses in all vegetable and fruit crops, in familial garden and natural areas.

Acromyrmex octospinosus (Reich 1793) has several common names and is known as ‘fourmi manioc’, ‘cassava ant’, ‘fourmi parasol’, ‘parasol ant’, ‘leaf-cutting ant’, ‘fungus-growing ant’, ‘sauba’, ‘bibijagua’, ‘bachaco’, ‘bachacs’, ‘sabanero’, ‘zompopo’, ‘sauva de matta’, ‘hormiga arriera’, ‘hormiga cortadora’ and ‘fourmi-man’. With *Atta sexdens* and *A. cephalotes*, this ant is one of the most important species of leaf-cutters because of its economic impact (Lewis 1975).

Fig. 1 Geographical distribution of the leaf-cutting ant *Acromyrmex octospinosus*. The ant is present in South and Central America and in the Caribbean and is classified among the most serious pests of tropical and subtropical America. It cans cause serious damages from 20 to 30 % of vegetable and fruit crops and losses were estimated at several million dollars per year

Although *A. octospinosus* is considered as an important pest, there is a lack of synthesis of information available on it. The aim of this chapter was to document the distribution, biology and control uses that can possibly be used to manage these leaf-cutting ants.

2 Geographical Distribution

A. octospinosus originated from South America and existed since the Cretaceous. This ant is present on its native continent (Curacao, Venezuela, Guyana, Surinam, French Guyana and Brazil), Central America (Mexico, Guatemala and Costa Rica) and in the Caribbean islands (Cuba, Guadeloupe, Carriacou, Grenada, Trinidad and Tobago) (Weber 1966; Discover Life 2012) (Fig. 1). *A. octospinosus* is thus found only in Neotropics ranging from Mexico to Brazil.

3 Biology and Behavior

A. octospinosus is a social insect whose colony can contain 1,000–20,000 individuals (Lewis 1975). The nests are underground, shallow (rarely beyond 50 cm deep) and often included in natural holes created by rocks, tree trunks or roots. They contain a fungus garden corresponding to the ant fungal symbiont (Weber 1966).

3.1 Reproduction

Males are haploid, winged and have no social function in the colony except fecundation during nuptial flights. They die after nuptial flights. Females are diploid and are differentiated by environmental and genetic factors in breeding females (future queens) or workers (Weber 1966). Breeding females (or gynes) are winged (Fig. 2) until nuptial flight where several males fertilize them. Each inseminated gyne becomes a queen and can lead a colony. Queen loses her wings, nests in the soil and begins to lay eggs. She starts cultivate the symbiotic fungus carried in her infrabuccal pocket. Queen survives thanks to digestion of flight muscles and abdominal fats. First larvae survive thanks to 'trophic' eggs that the queen laid. When first workers emerge, they feed the fungus cultivated by the queen and take over maintenance of the nest, eggs and larvae, leaving to the queen the function of laying (Quilan and Cherret 1978).

The juvenile stage (from egg to emergence) takes about 60 days. Eggs hatch out after 24 h and turn into larvae, which evolve in four stages for the workers and five for breeding females and males. Larvae become nymphs without pigmentation (Fig. 3). Pigmentation occurs gradually during the 18 days of this stage. Nymphs become light colored adults with insecure movements (Weber 1972).

Adult workers are wingless and equipped with eight spines on posterior part of thorax, a feature that is the origin of the species name of this ant. The species shows

Fig. 2 Breeding female or gyne (on the *left*) and inseminated female or queen (on the *right*) of the leaf-cutting ant *Acromyrmex octospinosus*. Gynes are winged until nuptial flight where several males fertilize them. Each inseminated gyne becomes a queen and can lead a colony. The queen loses her wings, nests in the soil and begins to lay eggs

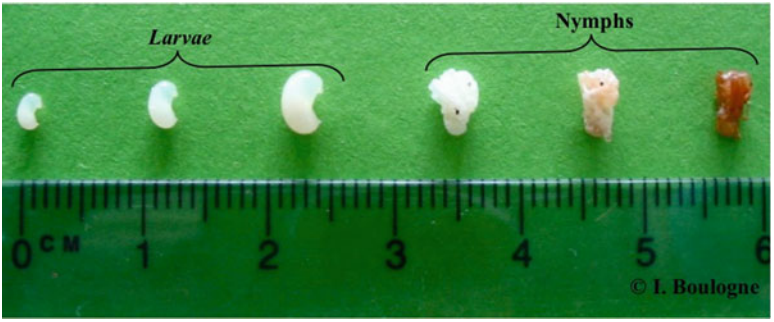

Fig. 3 Larvae and nymphs of the leaf-cutting ant *Acromyrmex octospinosus* at different stages. After the laying, eggs become larvae (in four or five stages), then nymphs without pigmentation and finally light colored adult ants

a high degree of worker size polymorphism with an extensive division of labor among size castes workers. They are divided into three castes (small workers or "minor", the medium worker or "media" and large workers or "major") (Wetterer 1991) (Fig. 4). It should be noted that workers may reproduce and lay eggs that develop haploid males. This reproduction is observed in orphan colonies (without queens). These 'haploid' reproductions are not observed in colonies with a queen, probably due to the chemical sterility maintained by the queen (Camargo et al. 2006).

Therefore a colony is divided into males, breeding females (or gyne) and three castes of workers (small workers or 'minor', medium workers or 'media' and large workers or 'major'). After nuptial flights, fertilized gynes can lead colonies by cultivating symbiotic fungus (carried in their infrabuccal pockets) and laying eggs. After the laying, eggs become larvae (in four or five stages), then nymphs and finally adult ants equipped with eight spines on posterior part of thorax (origin of the ant's species name).

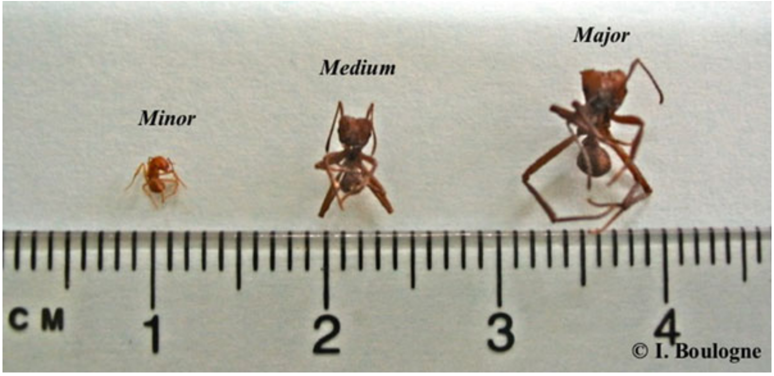

Fig. 4 Small workers or "minor", medium worker or "media" and large workers or "major" of the leaf-cutting ant *Acromyrmex octospinosus* equipped with eight spines on posterior part of thorax, a feature that is the origin of the species name of this ant. 'Major' workers cut and transport plant material to the nest, 'media' workers build the nest and defend it against external attacks while 'minor' workers take care about the symbiotic fungus, eggs, larvae and nymphs

3.2 Social Behaviour

Chemical signals from *A. octospinosus*, as other *Attini*, are indispensable supports of social life. Pheromones are the main signals emitted by the ants. They play a key role in colony organization. Trigger action pheromones are pheromones of trail and alarm. The latter is secreted by the mandibular gland and consists of 15 compounds, mainly octanone and octanol. The trail pheromone is secreted by the poison gland (or Dufours' gland) and consists mainly of dimethylpyrrole carboxylate, acetaldehyde and dimethyl-ethylpyrazine (Cross et al. 1982; Evershed and Morgan 1983). Queen pheromone changes the physiology of workers and induce nest attractiveness (Crewe and Blum 1972).

Colony work is distributed based on caste and ant size (Wilson 1980, 1983). The 'major' workers are between 7 and 10 mm and are responsible of cutting and transport of plant material to the nest. They also transport eggs, larvae and nymphs inside nest and take part in nest cleaning. The 'media' workers are 4–7 mm and are responsible for nest building, expansion, and defense against external attacks. They also clean out waste, rejected plant material and dead ants. The 'minor' workers are between 2 and 4 mm and are the most numerous. Their activity is essentially inside the nest where they take care about the fungus. They inoculate mycelium through the plant material with their fecal fluid. They also take care about eggs, larvae and nymphs. Taking care of larval stages includes (Camargo et al. 2006):

- licking larvae bodies, particularly oral and anal regions, in order to clean and sanitize them.
- larvae transport in several locations of nest in order to keep them in the best conditions of temperature and humidity and to protect them from disturbance of the nest.

- larvae nutrition performed by administration of chewing *gongylidia* (mycelium structure defined in paragraph below).
- ingestion of faecal fluid excreted by the larvae to exchange chemical trophalaxic messages between larvae and workers. This exchange is probably the way to collect larval secretions containing a chymotrypsin-like endopeptidase (enzyme missing in adult workers) that provide protein degradation.

Hence, pheromones are indispensable supports of social life of *A. octospinosus*. They can be classified into trigger action pheromones (pheromones of trail and alarm) and queen pheromones. Colony work is under pheromones actions and based on ant size: ‘major’ workers cut and transport plant material to the nest, ‘media’ workers build the nest and defend it against external attacks while ‘minor’ workers take care of the symbiotic fungus, eggs, larvae and nymphs.

3.3 Foraging

Foraging is conditioned by trail pheromone. When a major worker discovers an attractive plant material, it returns to the nest, leaving the pheromone on its path. The others workers are oriented along a pheromone gradient. Lengths of foraging trails range between 10 and 100 m depending on colony size (Moser 1967; Fowler 1978).

Foraging is a step process that takes place along a ‘line’ involving all castes of the colony. These steps are described follow (Weber 1966; Camargo et al. 2006):

- cutting the plant material (fresh and fallen leaves, stems, flowers, buds, fruits…) in nature;
- transport of this material in the nest;
- licking it;
- cutting these parts of plant into smaller pieces;
- chewing them;
- deposit of fecal fluid on chewing plant;
- deposit of mycelium fragment on plant substrate previously prepared and incorporation into the fungus garden.

Licking, cutting into smaller pieces and chewing plant material allow fungus to colonize quickly the substrate. Licking also serves to clean and sanitize plant material with antibiotics from the metapleural gland of workers that inhibit the growth of competing microorganisms. Fecal fluid allows a better plant degradation and a better colonization by the fungus thanks to pectinolytic and proteolytic enzymes and free amino acids it contains (Febvay and Kermarrec 1983; Camargo et al. 2006).

It follows that, foraging is conditioned by trail pheromone and takes place along a ‘line’ involving all castes of the colony. The foraging steps are: cut plant material, transport it into the nest, lick it, cut it into smaller pieces, chew it, depose fecal fluid on it, cultivate mycelium fragment on this prepared mixture and incorporate it into the symbiotic fungus.

4 Symbiosis

4.1 Fungi

The fungus symbiont is spongy and breakable and made with plant material and mycelium (Fig. 5). This 'fungus garden' has three parts: a superficial and young area called 'green and black' zone, a middle one called 'white' zone and an oldest basal one known as 'yellow' zone. Most authors agree that the symbiont is a Basidomycete, *Leucocoprinus gongylophorus* (Heim) Moeller (Hervey et al. 1977). At the microscopic level, spheroid swellings located at the apex of the mycelium, the *gongylidia* (grouped into *staphylae*) are specific for this fungus and are one of the recognition criteria (Fig. 6). The *gongylidium* is a differentiated organ protected by a thick wall whose contents a lot of nutrients particularly glycogen (Decharme 1978, 1980). G*ongylidia* are absorbed entirely by the larvae. They provide to them cell walls polysaccharides and cellular contents. Adult ants absorb only cellular contents, and keep mycelium cell walls in their infrabuccal pocket. In this pocket, the fungal cell walls are soaked with saliva, macerated and digested for 24 h thanks to chitinases and chitobiases of labial glands (Febvay et al. 1984). The fungus is the exclusive nutrition of both the juvenile stages and the queen. Fungus' cellular contents are a supplement of adult workers' diet. Their main diet is trophallaxic exchanges of plants sap.

Fig. 5 *Leucocoprinus gongylophorus*, basidomycete symbiont of the leaf-cutting ant *Acromyrmex octospinosus*, is made with plant material and mycelium and is the exclusive nutrition of both juvenile stages and the queen and is a supplement of adult workers' diet

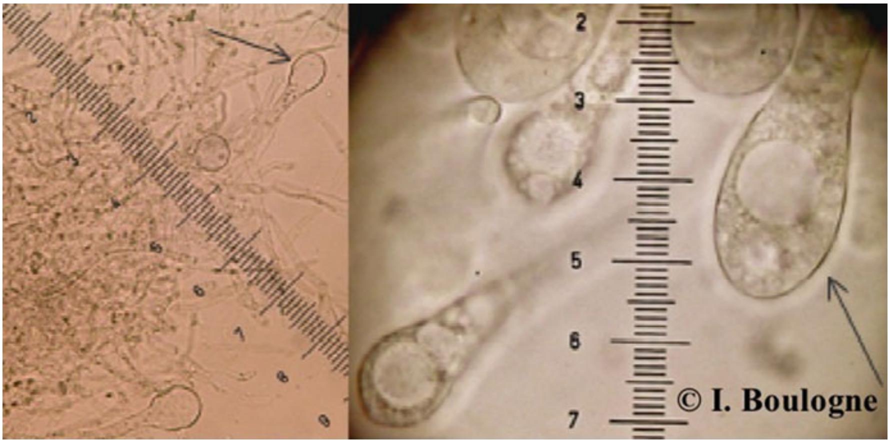

Fig. 6 *Gongylidium* shown by *black arrows* (grouped into *staphylae*), specific spheroid swellings of *Leucocoprinus gongylophorus*, basidomycete symbiont of the leaf-cutting ant *Acromyrmex octospinosus.* These *gongylidia* content a lot of nutrients particularly glycogen, are specific for this fungus and are one of the recognition criteria

Consequently, symbioctic fungus (or ‘fungus garden’) is a Basidomycete, *Leucocoprinus gongylophorus* (Heim) Moeller. It is spongy, breakable and made with plant material and mycelium. It is the exclusive nutrition of both the juvenile stages and the queen and is a supplement of adult workers’ diet.

4.2 Actinomycete

An actinomycete *Pseudonocardia* sp. grows on the cuticle of workers few days after emergence of insect and entirely covers its body between the 13th and 18th days. This ‘actinomycete coverage’ decreases between the 25th and 30th day for persisting only on latero-cervical area (Camargo et al. 2006). Queens vertically transmit this symbiont to entire colony. This symbiosis acts on fungus garden protection of fungal competitors like *Escovopsis* sp. (Ascomycete) (Fig. 7). It could also have protective action against ubiquist entomopathogenic bacteria and fungi. The benefit of this symbiosis for the actinomycete is not really known. There is probably a secretion of nutrients on ant cuticle that increase actinomycete growth. This fact might explain actinomycete localization, which depending on ant age. Indeed, young soft ant cuticle might allows establishment and nutrition of actinomycete on the entire young insect body. Older ants cuticle is less soft and actinomycete might only grows on cervical areas (Currie et al. 2003).

Therefore the actinomycete *Pseudonocardia* sp. (vertically transmitted by queens) grows on the cuticle of all ants of the colony. This symbiont protects fungus garden against fungal competitors and ants against ubiquist entomopathogenic bacteria and fungi. The exact benefit of this symbiosis for the actinomycete is not really known.

Fig. 7 Nests of the leaf-cutting ant *Acromyrmex octospinosus* where *Leucocoprinus gongylophorus* the basidiomycete symbiont is invaded by *Escovopsis* sp, a fungal competitor. In normal conditions, the actinomycete *Pseudonocardia* sp., which grows on the cuticle of all ants of the colony, protects the basidiomycete symbiont against this fungal competitor

5 Economic and Natural Losses

A. octospinosus causes serious damages due to its foraging activity. Calculating the losses resulting from this leaf-cutting ant attack is difficult due to the wide range of damages they cause (Knapp 1987). Damage can represent from 20 to 30 % of the production of some crops and financial losses are enormous in every country where it occurs. The United States Department of Agriculture (USDA) classifies this ant among the most serious pests of tropical and subtropical America (Pollard 1982).

In Trinidad, a study estimated that *Acromyrmex octospinosus* nests could remove 20–25 % of the total leaf area in the first year of a crop of cacao or citrus orchards. This was equivalent to a tree mortality of 6–17 % resulting from defoliation (Lewis 1975; Pollard 1982). In 1968 annual losses due to *A. octospinosus* activities were estimated at US$250,000 in this country (Pollard 1982).

In Guadeloupe (FWI), *A. octospinosus*, was discovered in 1954 in the vicinity of the Morne-à-l'eau community on the island of Grande Terre (Mikheyev 2008). This species used to be considered only as an agriculture pest. However, a Regional Federation of Defense against Pests (FREDON) survey carried out in 2008 indicated that the ant is present on the whole territory of Guadeloupe. This survey shows that vegetable and fruit crops account for 90.9 % of attacks. The ant has also invaded natural areas in favor of the cyclone of 1995. Constantly expanding, it is found at over 700 m of altitude and is now threatens plant species of protected areas, in particular arborescent ferns of *Cyathea* sp. of rain forest. Some of those may completely disappear due to their endemism.

A. octospinosus is thus classified among the most serious pests of tropical and subtropical America. Due to its foraging activity, it can cause serious damages from 20 to 30 % of crop production. Huge losses were observed in several vegetable and fruit crops, in crop of cacao or citrus orchards and in protected areas (where some species may completely disappear due to their endemism).

6 Pest Management

6.1 Physical Management

The first techniques used to fight against *A. octospinosus* were physical and mechanical methods. They are still in use and consist in flooding, digging, burning, dynamiting or pumping smoke into nests. These methods have only local efficacy and do not prevent from individuals survivors reestablishing the colony (Knapp 1987).

Therefore first techniques used to fight against *A. octospinosus* were mechanical methods, which have only local efficiency and do not prevent from the reestablishment of colonies.

6.2 Synthetic Chemical Management

Chemical control began at the twentieth century and intensified with the Green Revolution. It can be classified into (i) direct application of chemicals and (ii) laying of toxic baits.

Direct chemical control can be applied through liquids, dusts, vapours or thermal fogs. This chemical management was first organized with insecticides and fungicides such as hydrogen cyanide gas, sulfur dioxide, sulfur and arsenic vapors, carbon disulphide or chloropicrin. After 1960, it was fulfilled with synthetic insecticides such as organochlorines: lindane, chlordane, heptachlor, aldrin and dieldrin (Pollard 1982). The efficiency of these products varied. It can disturb the colony or kill some larvae and workers. In most case, survived ants may just abandon the nest and build a new one. Moreover substances used are toxic for humans by contact, ingestion or inhalation and are hazardous for environment. Direct chemical control requires also significant human resources for the work of prospecting and tracking nests.

First uses of toxic baits began in 1963. These baits were made up with agricultural by-products (sugar cane waste, citrus pulp and soybean oil). Their efficiency has been limited and tropical climate induces fermentation and microbial growth in bait (Cherrett 1969). In 1964, began Mirex® use whose active insecticidal ingredient was perchlordecone. The active ingredient was released to whole colony by trophallaxis. Attractiveness and efficiency of the baits were ephemeral. In addition, active substance was toxic to humans, highly volatile and hazardous for environment. In 1984, laboratory and *in situ* tests were made with AMDRO (Hydramethylnon), an amidinohydrazone. Baits were made with wheat flour, malting residue or sugarcane residue and soybean oil. This bait missed attractiveness and was weakly efficient on the entire colony. Microencapsulation appeared in 1984. Insecticide was enclosed in a microscopic capsule where active substance was spreading out slowly. Size of microcapsules must be between a few microns and 1 mm in order to be blocked in ant infrabuccal filter (Febvay 1982). This method is less toxic than others pesticides for mammals and birds, but still toxic for bees.

In France (Guadeloupe, FWI), pest management starts in 1956 and until 1963, it consisted in nests exploration and direct application of lindane and heptachlor inside them. From 1963 to 1973, aldrin baits are used until they were forbidden in France. In 1968, Mirex 450® (0.45 % perchlordecone) appeared and was intensively used after 1970. It was sold to farmers and common people as granules baits to put at the entrance of nests (Febvay et al. 1990). The perchlordecone is a neurotropic organochlorine that affects sodium channels function needs for the transmission of nervous impulses of insects. This molecule can be degrade to chlordecone and is bioaccumulative, induce insects resistance and is responsible of pollution of soil, water and plants (Cabidoche et al. 2006). Although banned by US Environmental Protection Agency before 1986, Mirex 450® was only forbidden in France in 1993. From 1994 to 2003, Department of Plant Protection has authorized the use of Mirex S® whose active substance was sulfluramid. The sulfuramid give perfluorooctane sulfonate (PFOS) after degradation. PFOS is a persistant organic pollutant whose adverse effects are very important for human health and environment (UNEP 2007). Since 2003, the active substance authorized by the Ministry of Agriculture and Fisheries for *A. octospinosus* pest management is fipronil at 0.03 g/kg (Blitz®). Fipronil (5-amino-3-cyano-1-(2.6-dichloro-4-trifluoromethyl-phenyl)-4trifluoromethylsulfinylpyrazole), is a phenylpyrazole. Fipronil is a noncompetitive inhibition of GABAergic synapses, alters invertebrate's nerve cells chlorine pumps, inhibits electric control, and induces a hyperexcitability. It is insecticidal by ingestion (Toral 2005).

In 2012, this substance is still used and widely marketed although its environmental toxicity (Official Journal of the French Senate of 17/11/2005, page 2969; UNEP 2007). We have to mention the fact that this substance, as an endocrine disruptor, can also have significant impact on public health (AFSSA 2005).

Thus chemical control against *A. octospinosus* began in the twentieth century with a direct chemical control. It was applied through liquids, dusts, vapours or thermal fogs of hydrogen cyanide gas, sulfur dioxide, sulfur and arsenic vapors, carbon disulphide, chloropicrin or organochlorines. Since 1963, toxic baits (with perchlordecone, hydramethylnon, sulfluramid or fipronil) were successively used. The efficiency of these controls has been limited but all of them were toxic for humans and hazardous for environment.

6.3 Sustainable Pest-Management

First laboratory tests for biological control began in 1939. They consisted in introducing conidial spores of pathogenous fungus into nest. Efficacy of this method was limited because diseases didn't really include in nest and pathogens spores were released by workers. In the same period, field tests consisting in the introduction of ants predators like Acarians, Collembolas and *Phoridae* sp. flies were achieved. The method was not sufficient to reduce ant populations. In 1970, laboratory and field tests were performed with fungal symbiont's extract and trail pheromone (the compound M4MP2C) (Knapp 1987). *In vitro* efficiency of this test was not being confirmed *in situ*.

Laboratory trials were conduced with entomopathogenic fungus *Entomophthora coronata* (Kermarrec and Mauleon 1975) and the nematodes *Heterorhabditis* sp. and *Neoaplectana* sp. (Kermarrec et al. 1988). These trials did not give the desired effect on *Acromyrmex octospinosus*. In 2007, other tests were performed on other Attines of the genus *Atta* using entomopathogenic fungi *Metarhizium anisopliae, Beauveria bassiana* and *Trichoderma viride* (Da Silva and Diehl-Fleig 1988; Lopez and Orduz 2003; Santos et al. 2007). These tests allowed producing a microbiological insecticide: the BIBISAV®. Unfortunately, this product did not seem to have the same effect on *A. octospinosus* (Machado et al. 1988). Another study was perform with a different formulation of *Beauveria bassiana* BIBISAV-2® which seemed to be capable to reduce activity of *A. octospinosus* (Perez and Trujillo 2002).

Another alternative to chemical control has been explored with the insecticidal activities of plants extracts. Insecticidal activity of two rotenoids (isoflavonoids) extracted from *Lonchocarpus* sp. (Fabaceae) was shown on *Acromyrmex octospinosus* (Petit 2004). *Mammea americana*, *Nerium oleander*, *Nicotiana tabacum*, *Rollinia mucosa* and *Trichillia palida* plant extracts showed various effects on *A. octospinosus* workers (contact toxicity, repellent activity and/or toxicity by ingestion) (Boulogne et al. 2012a).

Other alternative control has been explored on the fungal symbiont. Fungicidal activities of organic extracts of plants were tested. *Allium cepa*, *Allium sativum*, *Lycopersicon esculentum*, *Manihot esculenta* and *Senna alata* plant extracts showed various effects on *Leucocoprinus gongylophorus in vitro* cultures (Boulogne et al. 2012b). Results of these tests based on insecticidal and fungicidal plants extracts as an alternative to synthetic chemical control showed very encouraging *in vitro* preliminary results. Indeed natural insecticides and fungicides may serve as alternatives to synthetic compounds to develop safer control agents of leaf-cutting ants.

Hence, since 1939, laboratory and field tests of biological control were performed with introduction of conidial spores of pathogenous fungus or ants predators into nest, with fungal symbiont's extract and trail pheromone, with entomopathogenic fungus and nematodes. The efficiency of most of these methods was limited, did not give the desired effect or were not confirmed *in situ*. Another alternative to chemical control has been explored with the insecticidal or fungicidal activities of plants extracts, which showed various effects on *A. octospinosus* workers (contact toxicity, repellent activity and/or toxicity by ingestion) and various effects on *Leucocoprinus gongylophorus in vitro* cultures. These tests showed very encouraging *in vitro* preliminary results and may serve as alternatives to synthetic compounds to develop safer control agents of leaf-cutting ants.

6.4 Integrated Pest-Management

As shown in Fig. 8 (*Pseudonocardia*'s picture is taken from Park et al. 2008), complex relationships between ant, fungus and actinomycete are involved. In this tripartite

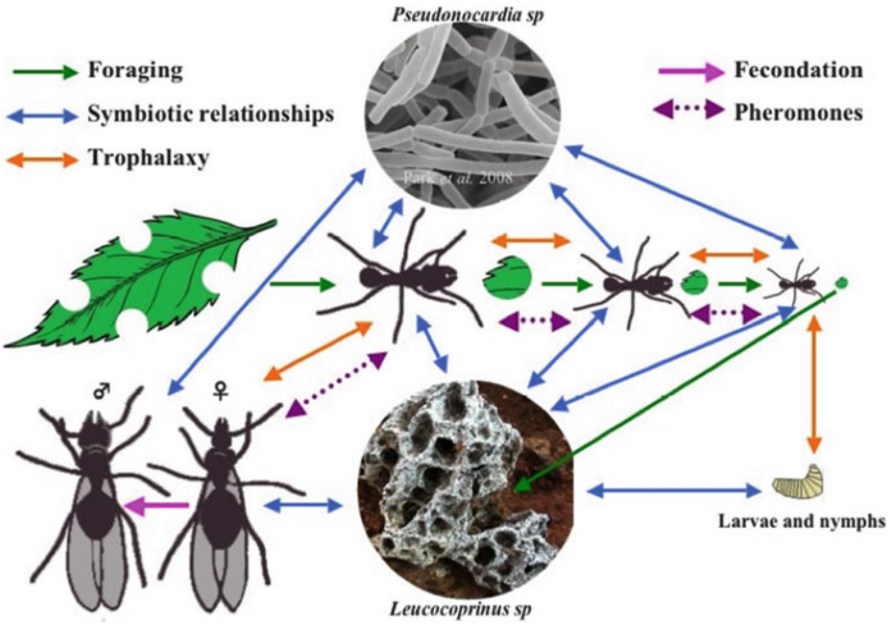

Fig. 8 Complex relationships and tripartite mutualism in nests of the leaf-cutting ant *Acromyrmex octospinosus* between ants, basidomycete symbiont *Leucocoprinus gongylophorus* and actinomycete symbiont *Pseudonocardia* sp. (*Pseudonocardia*'s picture is taken from Park et al. 2008). Social life of *A. octospinosus* is under pheromones actions (trail, alarm and queen pheromones). Foraging is conditioned by trail pheromone and takes place along a 'line' involving all castes of the colony. There are trophallaxic exchanges between larvae and workers and between workers, queen, gynes and males. *Leucocoprinus gongylophorus* is the exclusive nutrition of both the juvenile stages and the queen and is a supplement of adult workers' diet. *Pseudonocardia* sp protects *Leucocoprinus gongylophorus* against this fungal competitor and *A. octospinosus* against entomopathogens

mutualism, fungus serves as primary food source for ants, the actinomycete helps to protect the fungus from specialized parasites and ants take care of the fungus and disperse both fungus and actinomycete to new colonies (Currie 2001). In all studies only one side management was investigated: the insecticidal or the fungicidal level individually.

First we thought that a combination of both strategies should promote a more efficient integrated control. It is the reason why a previous literature review indicated 20 interesting chemicals with both insecticidal and fungicidal activities and 305 plant species containing these chemicals were found (Boulogne et al. 2012c).

Then we hypothesize that, like tripartite mutualism, the management of *A. octospinosus* requires a tripartite management based on a combination of the three strategies.

Consequently we suggest in future studies on the control of *A. octospinosus* that trials focusing on control methods should be conducted for the investigation of alternatives acting simultaneity on ant, fungus and mutualistic actinomycete. In literature, it has not existing data on effect of alternatives on *Pseudonocardia* sp strains. Early in vitro studies should therefore been conducted on cultures of *Pseudonocardia* by testing substances of plant origin known for their antibacterial and antifungal activities.

Complex relationships and tripartite mutualism are then involved between ants, fungus and actinomycete. All studies investigated only one side management: insecticidal or the fungicidal level individually. A combination of both strategies or a tripartite management based on a combination of the three strategies should promote a more efficient integrated control.

7 Conclusion

Although *Acromyrmex octospinosus* is considered as an important pest, there is a lack of synthesis of information available on it. This fact is probably one of the reasons why there is no effective control of this pest. In addition synthetic chemicals used are not really efficient but hazardous for the environment and human health. Alternative solutions must be quickly found. Several attempts of biological control did not give expected results on *A. octospinosus*. Nevertheless plants extracts gave good results and seemed to have the potential to fight against this insect. Further studies will complete and refine previous works and explore new paths. A combined integrated tripartite pest management (against fungus, insect and actinomycete) with eco-friendly extracts of plant origin could be a solution to explore for efficient and sustainable control of *A. octospinosus*.

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Impact of Pesticide Productivity on Food Security

József Popp, Károly Pető, and János Nagy

Abstract The seven billion global population is projected to grow by 70 million per annum, increasing by 30 % to 9.2 billion in 2050. This increased population density is projected to increase demand for food production by 70 % notably due to changes in dietary habits in developing countries towards high quality food, e.g. greater consumption of meat and milk products, and to the increasing use of grains for livestock feed. The availability of additional agricultural land is limited. Furthermore, more agricultural land will be used to produce bio-based commodities such as bioenergy or fibre instead of food and feed. Thus, we need to grow food on even less land, with less water, using less energy, fertiliser and pesticide than we use today. Given these limitations, sustainable production at elevated levels is urgently needed. The reduction of current yield losses caused by pests are major challenges to agricultural production. This review presents (1) worldwide crop losses due to pests, (2) estimates of pesticide-related productivity, and costs and benefits of pesticide use, (3) approaches to reduce yield losses by chemical, as well as biological and recombinant methods of pest control, and (4) the challenges of the crop protection industry. However, as long as there is a demand for pesticide-based solutions to pest control problems and food security concerns, the externality problems associated with the human and environmental health effects of pesticides needs also to be addressed.

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Keywords Pest control • Pesticide use • Benefits • Externality • Crop protection industry

1 Introduction

The combined effect of the Green Revolution has allowed world food production to double in the past 50 years. From 1960 to present the human population has more than doubled to reach seven billion people. In 2050, the population is projected to increase by 30 % to about 9.2 billion (Fig. 1). Due to increasing global population and changing diets in developing countries towards meat and milk products demand for food production is projected to increase by 70 % (FAO 2009).

Globally, an average of 35 % of potential crop yield is lost to pre-harvest pests (Oerke 2005). In addition to the pre-harvest losses, food chain losses are also relatively high (IWMI 2007). Agriculture has to meet at a global level a rising demand for food, feed, fibre, bioenergy and other bio-based commodities, however, the provision of additional agricultural land is limited. Given these limitations, sustainable production and increasing productivity on existing land is by far the better choice (Fig. 2). Part of the key is also to avoid waste along the whole length of the food chain. Much of the increases in yield per unit of area can be attributed to more efficient control of (biotic) stress rather than an increase in yield potential.

In order to safeguard the high level of food and feed productivity necessary to meet the increasing human demand, these crops require protection from pests (Popp 2011). Helping farmers lose less of their crops will be a key factor in promoting

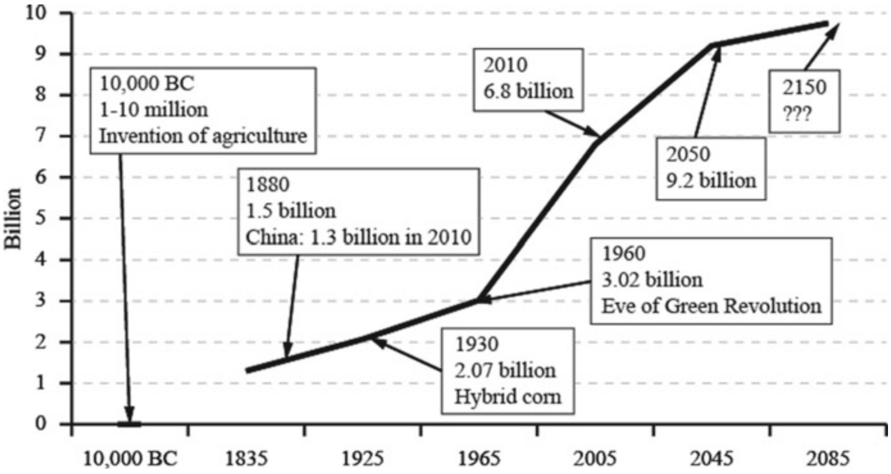

Fig. 1 World population growth. From 1960 to present the human population has more than doubled to reach seven billion people and in 2050, the population is projected to increase by 30 % to about 9.2 billion (Source: FAO 2009)

Fig. 2 Livestock food in the diet. Copyright: FAO/L.Rlung (FAO 2011)

food security. The beneficial outcome from use of pesticides provides evidence that pesticides will continue to be a vital tool in the diverse range of technologies that can maintain and improve living standards for the people of the world (National Research Council 2000).

Globally, agricultural producers apply around USD 40 billion worth of pesticides per annum. The market share of biopesticides is only 2 % of the global crop protection market (McDougall 2010). Farmers in highly developed, industrialised countries expect a four or five fold return on money spent on pesticides (Gianessi and Reigner 2005, 2006; Gianessi 2009). Can we meet world food demands if producers continue, increase or discontinue pesticide use because of reduced economic benefits? This is the greatest challenge facing scientists in history between now and the year 2050 (Popp 2011).

2 Crop Losses to Pests

An average of 35 % of potential crop yield is lost to pre-harvest pests worldwide (Oerke 2005). In addition to the pre-harvest losses transport, pre-processing, storage, processing, packaging, marketing and plate waste losses along the whole food chain account for another 35 % (Fig. 3). In addition to reduce crop losses due to pests avoiding waste along the whole length of the food chain is also key (Popp 2011). Crop protection has been developed for the prevention and control of crop losses due to pests in the field (pre-harvest losses) and during storage (post-harvest losses). This chapter concentrates on pre-harvest losses, i.e. the effect of pests on

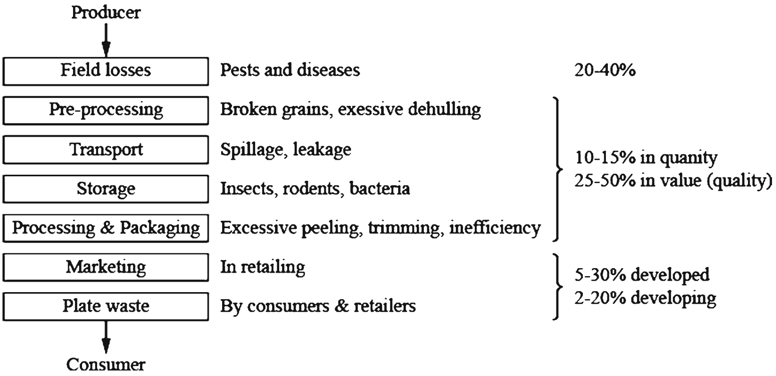

Fig. 3 Losses along the food chain. An average of 35 % of potential crop yield is lost to pre-harvest pests worldwide. In addition to the pre-harvest losses transport, pre-processing, storage, processing, packaging, marketing and plate waste losses along the whole food chain account for another 35 % (Source: IWMI 2007)

crop production in the field, and the effect of control measures applied by farmers in order to minimise losses to an acceptable level (Oerke 2005).

The assessment of crop losses is important for demonstrating where future action is needed and for decision making by farmers as well as at the governmental level. According to German authorities in 1929, animal pests and fungal pathogens each caused a 10 % loss of cereal yield. In potato, pathogens and animal pests reduced production by 25 % and 5 %, respectively; while in sugar beet, production was reduced by 5 % and 10 % due to pathogens and animal pests respectively (Morstatt 1929). In the USA, in the early 1900s pre-harvest losses caused by insect pests were estimated at seldom less than 10 % (Marlatt 1904).

Estimates of actual losses in crop production worldwide were updated for the period 1988–1990 on a regional basis for 17 regions by Oerke et al. (1994). Increased agricultural pesticide use nearly doubled food crop harvests from 42 % of the theoretical worldwide yield in 1965 to 70 % of the theoretical yield by 1990. Unfortunately, 30 % of the theoretical yield was still being lost because the use of effective pest management methods was not applied uniformly around the world and it still is not. Without pesticides 70 % of crop yields could have been lost to pests (Oerke 2005).

Since crop production technology and especially crop protection methods are changing continuously, loss data for eight major food and cash crops – wheat, rice, maize, barley, potatoes, soybeans, sugar beet and cotton – have been updated for the period 1996–1998 on a regional basis for 17 regions (Oerke and Dehne 2004). Among crops the loss potential of pests worldwide varied from less than 50 % (on barley) to more than 80 % (on sugar beet and cotton). Actual losses were estimated at 26–30 % for sugar beet, barley, soybean, wheat and cotton, and 35 %, 39 % and 40 % for maize, potatoes and rice, respectively (Oerke and Dehne 2004).

Table 1 Estimates of actual crop losses due to pests in worldwide production of wheat, maize and cotton

		Actual loss (%)			
Period	Yield (kg/ha)	Weeds	Animal pests	Diseases	Total
Wheat					
1964/1965[a]	1,250	9.8	5.0	9.1	23.9
1988–1990[b]	2,409	12.3	9.3	12.4	34.0
1996–1998[c]	2,610	9.0	8.0	12.0	29.0
2001–2003[d]	2,691	7.7	7.9	12.6	28.2
Maize					
1964/1965[a]	2,010	13.0	12.4	9.4	34.8
1988–1990[b]	3,467	13.1	14.5	10.8	38.3
1996–1998[c]	4,190	10.0	10.0	10.0	30.0
2001–2003[d]	4,380	10.5	9.6	11.2	31.2
Cotton					
1964/1965[a]	1,029	4.5	11.0	9.1	24.6
1988–1990[b]	1,583	11.8	15.4	10.5	37.7
1996–1998[c]	1,630	7.0	12.0	10.0	29.0
2001–2003[d]	1,702	5.6	12.3	7.9	28.8

Source: Cramer (1967), Oerke et al. (1994), Oerke and Dehne (2004), and Oerke (2005) and own calculations

Worldwide estimates for losses to pests in 1996–1998 and 2001–2003 differ significantly from estimates published earlier

[a] From Cramer (1967)

[b] From Oerke et al. (1994)

[c] From Oerke and Dehne (2004)

[d] From Oerke (2005)

Since the early 1990s, production systems and especially crop protection methods have changed significantly, especially in crops like maize, soybean and cotton, in which the advent of transgenic varieties has modified the strategies for pest control in some major production regions. Loss data for major food and cash crops have been updated most recently by Commonwealth Agricultural Bureaux International's Crop Protection Compendium for six food and cash crops – wheat, rice, maize, potatoes, soybeans, and cotton – for the period 2001–2003 on a regional basis (CABI's Crop Protection Compendium 2005; Oerke 2005). Nineteen regions were specified according to the intensity of crop production and the production conditions. Among crops, the total global potential loss due to pests varied from about 50 % in wheat to more than 80 % in cotton production. The responses are estimated as losses of 26–29 % for soybean, wheat and cotton, and 31 %, 37 % and 40 % for maize, rice and potatoes, respectively.

Worldwide estimates for losses to pests in 1996–1998 and 2001–2003 differ significantly from estimates published earlier (Cramer 1967; Oerke et al. 1994). Obsolete information from old reports has been replaced by new data. Alterations in the share of regions differing in loss rates in total production worldwide are also responsible for differences (Table 1). Moreover, the intensity and efficacy of crop protection has increased since the late 1980s especially in Asia and Latin America where the use of pesticides increased above the global average (Yudelman et al. 1998). above the global average (Yudelman et al. 1998).

3 Estimates of Pesticide-Related Productivity

The use of pesticides has increased dramatically since the early 1960s; in the same period also the yield average of wheat, rice and maize, the major sources for human nutrition, has more than doubled. Without pesticides, food production would drop and food prices would soar. Where overall crop productivity is low, crop protection is largely limited to some weed control and actual losses to pests may account for more than 50 % of the attainable production (Oerke 2005). Use patterns of pesticides vary with crop type, locality, climate, and user needs. Plant disease can be devastating for crop production, as was tragically illustrated in the Irish potato famine of 1845–1847. This disaster led to the development of the science of plant pathology (Agrios 1988). From the time when synthetic pesticides were developed after World War II, there have been major increases in agricultural productivity accompanied by an increase in efficiency, with fewer farmers on fewer farms producing more food for more people.

Ensuring the safety and quality of foods and the increase in crop loss was accompanied by a growth in the rate of pesticides use. The annual global chemical-pesticide market is about three million tonnes associated with expenditures around USD 40 billion (Popp 2011). The growing dependence on chemical pesticides has been called the "pesticide treadmill" by entomologists (Bosch 1978). A major factor in the "pesticide treadmill" involves two responses to pesticide resistance. The first is to increase the dose and frequency of use of the less effective pesticide; this typically results in higher levels of pest resistance and damage to natural enemies and the environment. The second response is to develop and commercialise a new pesticide. The treadmill concept assumes that this two-step process will continue until the pest meets a resistance-proof pesticide or until the supply of effective new pesticides is exhausted. The greater the impact of control measures on pest populations, the more extreme are their evolutionary responses. However, the moderate rates in yield increase in the major world crops during 1965–2000 did not offer a strong case for a high increase in pesticide use even taking into account the fair amount of change in the cropping systems of developing countries with an expansion of the fruits and vegetable sector (FAO 2000).

Pesticide productivity has been estimated in three general ways: with partial-budget models based on agronomic projections, with combinations of budget and market models, and with econometric models. The most widely cited studies on pesticide productivity, those of Pimentel (Pimentel et al. 1978, 1991, 1992), Cramer (1967) and Knutson et al. (1993) use partial-budget models. One of these studies (Pimentel et al. 1991) estimates that aggregate crop losses amounted to 37 % of total output in 1986, up from 33 % in 1974. In comparison, Cramer (1967) estimated crop losses of around 28 % due to all pests in all of North and Central America. Estimates of crop losses at 37 % are questionably high. Crop losses of the magnitude estimated by Pimentel et al. (1991) should be sufficient to make it profitable to use chemical pest controls at much greater rates than observed today.

Other studies have attempted to estimate pesticide related effects of large reductions in pesticide use by combining partial-budget models with models of output markets (Zilberman et al. 1991; Ball et al. 1997). These studies use the same approach as partial-budget models in estimating yield and cost effects of changes in pesticide use. The productivity of pesticides – and thus the effects of reducing pesticide use – depends in large measure on substitution possibilities within the agricultural economy (Zilberman et al. 1991). In general, pesticide productivity will tend to be low in situations where substitution possibilities are large. Real prices of energy and durable equipment have fallen relative to agricultural chemical prices (Ball et al. 1997). On the other hand the prices of hired and self-employed labour have risen steadily, both in real terms and relative to agricultural chemical prices, and this suggests that labour-intensive pest-control methods have become less attractive relative to pesticide use. Zilberman et al. (1991) estimated that every dollar increase in pesticide expenditure raises gross agricultural output by USD 3–6. Most of that benefit is passed on to consumers in the form of lower prices for food.

Econometric models capture all forms of substitution in production, including short-term and long-term substitutes for pesticides on individual farms and at the regional and national levels. Headley (1968) estimated such a model by using state-level cross-sectional data in the US for the year 1963. He used crop sales to measure output and expenditures on fertilisers, labour, land and buildings, machinery, pesticides and other inputs as measures of input use and found that an additional dollar spent on pesticides increased the value of output by about USD 4 showing a high level of productivity for that period. The Headley model generates estimates of the marginal productivity associated with pesticides, that is, the additional amount (value) of output obtained by using an additional unit of pesticides. Multiplying the marginal productivity of pesticides by the quantity of pesticides used thus understates the total value added by pesticides (Pimentel et al. 1992). Carrasco-Tauber and Moffitt (1992) applied this approach to state-level cross-sectional data on sales and input expenditures in the U.S. like those used by Headley (1968). Their use of sales as a dependent variable generated an implicit estimate of aggregate US crop losses in 1987 of 7.3 % at average pesticide use, far less than estimates of other studies (Pimentel et al. 1991; Oerke et al. 1994). Chambers and Lichtenberg (1994) developed a dual form of this model based on the assumptions of profit maximisation and separability between normal and damage-control inputs. Implicit crop losses in 1987 estimated from those models ranged from 9 % to 11 %, only about one quarter to one third of the size estimated by others (Pimentel et al. 1991; Oerke et al. 1994). Estimated crop losses with zero pesticide use ranged from 17 to 20 %.

4 Costs and Benefits of Pesticide Use

The economic analyses of pesticide benefits is hindered by the lack of pesticide use data and economic models for minor crops and non-agricultural pesticides. Cost-benefit analysis is increasingly used to assess resource management and environmental policies. The most commonly recognised economic incentives are based on the "polluter pays" principle, including the use of licensing fees, user fees or taxes. The experience of those countries (Denmark, Sweden and Norway) that have introduced these taxes is that they appear to have played some role in reducing pesticide use. However, their price elasticity estimates are low and this suggests comparatively little effect in terms of quantity reductions, unless they are set at very high rates relative to price. There is some suggestion that revenue recycling may have been more effective, with revenues redirected to research and information. Using revenues to further research or encourage changes in farming practice would appear to make more sense (Pearce and Koundouri 2003).

Nevertheless, the "polluter pays" principle (i.e. adding the environmental and public health costs to the price paid by consumers) can be an effective approach to internalise the social costs of pesticide use. The fees and taxes generated can be used to promote improved (sustainable) pest management. In order to set the right level of levies and taxes, it may be necessary to calculate the negative impacts of pesticides. Various attempts have been made to determine the costs that relate to public health (risks to farm workers and consumers, and drift risk), and damage to beneficial species, and to the environment (Pimentel et al. 1992; Pimentel and Greiner 1997; Pimentel 2005). However, pesticides can result in a range of benefits including wider social outcomes with benefits being manifested in increased income and reduced risk, plus the ability to hire labour and provide employment opportunities. Other outcomes were the evolution of more complex community facilities, such as schools and shops, and improved health (Bennett et al. 2010).

The costs of pesticides and non-chemical pest control methods alike are low relative to crop prices and total production costs. Pesticides account for about 7–8 % of total farm production costs in the EU. However, there is wide variation among Member States fluctuating between 11 % in France and Ireland and 4 % in Slovenia (Popp 2011). Pesticides account for 5–6 % of total farm input in monetary terms in the USA (USDA 2010).

Overall, farmers have sound economic reasons for using pesticides on crop land. The global chemical-pesticide market is about three million tonnes associated with expenditures around USD 40 billion in a year. As a result of the increasing use of GM herbicide tolerant and insect resistant crop seed and sales of agrochemicals used in non-crop situations (gardening, household use, golf courses, etc) the value of the overall crop protection sector is estimated to reach about USD 55 billion. The increasing sale of GM seeds has had a direct impact on the market for conventional agrochemical products (McDougall 2010). In spite of the yearly investments of nearly USD 40 billion worldwide, pests cause an estimated 35 %

Table 2 Value of herbicides, insecticides and fungicides in U.S. crop production

USD billion	Herbicides 2005	Insecticides 2008	Fungicides 2002	Total 2002–2008
Cost to growers	7.1	1.2	0.9	9.2
Non-use cost increase	9.7	–	–	9.7
Yield benefit	16.3	22.9	12.8	52.0
Net benefit	26.0	21.7	12.0	59.7
Return ratio: benefit/cost (USD)	3.7	18.1	13.3	6.5

Source: Gianessi and Reigner (2005, 2006), Gianessi (2009) and own calculations
In the US. pesticide use saves around USD 60 billion on crops that otherwise would be lost to pest destruction indicating a net return of USD 6.5 for every dollar that growers spent on pesticides and their application

actual loss (Oerke 2005). The value of this crop loss is estimated to be USD 2,000 billion per year, yet there is still about USD 5 return per dollar invested in pesticide control (Pimentel 2009).

According to the national pesticide benefit studies in the United States, USD 9.2 billion are spent on pesticides and their application for crop use every year (Gianessi and Reigner 2005, 2006; Gianessi 2009). This pesticide use saves around USD 60 billion on crops that otherwise would be lost to pest destruction. It indicates a net return of USD 6.5 for every dollar that growers spent on pesticides and their application. However, the USD 60 billion saved does not take into account the external costs associated with the application of pesticides in crops (Table 2).

Obviously, when pesticides are not used correctly, then the socio-economic and environmental benefits may not be realised and the economic damage resulting from widespread pesticide use should also be highlighted. The environmental and public health costs of pesticides necessitate the consideration of other trade-offs involving environmental quality and public health when assessing the net returns of pesticide usage. Pimentel (2005) found that pesticides indirectly cost the U.S. USD 9.6 billion a year including losses from increased pest resistance; loss of natural pollinators (including bees and butterflies) and pest predators; crop, fish and bird losses; groundwater contamination; and harm to pets, livestock and public health. Should the past assessments of environmental and social impact be narrow and should they be broadened to USD 20 billion per year the previous estimate of USD 60 billion worth of production benefits to the U.S. from pesticide use would be lower (USD 40 billion) if net effects are considered. However, the net benefit still shows a high profitability of pesticides indicating a net return of USD 3 for every dollar spent on pesticides (Popp 2011).

Genetically engineered organisms that reduce pest pressure constitute a “new generation” of pest-management tools. Biotechnology has delivered economic and environmental gains through a combination of their inherent technical advances and the role of the technology in the facilitation and evolution of more cost effective and environmentally friendly farming practices.

5 Biopesticides and Integrated Pest Management

Biopesticides offer important social benefits, as compared with conventional pesticides. Yet in an agricultural industry that is still dominated by pesticides, biological control has found its place in the form of augmentative releases, particularly for the management of pests that are difficult to control with insecticides. There has been a strong tendency to consider biopesticides as “chemical clones” rather than as biological control agents, and therefore the chemical pesticide model has been followed. On the other hand, regulation of biopesticides is needed because being “natural” does not mean it is safe. However, the challenge of new and more stringent chemical pesticide regulations, combined with increasing demand for agriculture products with positive environmental and safety profiles, is boosting interest in biopesticides. It takes an average of 3–6 years and USD 15–20 million to develop and register a biopesticide compared with 10 years and USD 200 million for synthetic pesticides (REBECA 2007). Many of the major pesticide manufacturers are jumping into the biopesticide industry (Fig. 4).

Global sales of biopesticides are estimated to total around USD 1 billion, still small compared to the USD 40 billion in the worldwide pesticide market. It is pegged at around 2 % of the global crop protection market (Popp 2011). While biopesticides may be safer than conventional pesticides, the industry is composed mostly of small to medium sized enterprises and it is difficult for one company to fully and comprehensively fund research and development, field development and provide the marketing services required to make a successful biopesticide company. Another challenge is the lack of innovative biopesticide products coming to the marketplace and their registration (Farm Chemical Internationals 2010).

Fig. 4 Landscape in Hungary (Copyright: Popp 2012)

During the past two decades, IPM (Integrated Pest Management) programmes have reduced pest control costs and pesticide applications in fruit, vegetable and field crops. For farmers, very often the main benefit of IPM is the avoidance of uneconomical pesticide use. However, a large part of the benefits are reduction of externalities and therefore occur to other groups. This poses considerable measurement and valuation problems. Although the IPM programmes did reduce pesticide use, most of the programmes still relied heavily on pesticides. The institutional environment for IPM at the global level has become more complex. For the pesticide market, liberalisation without effective regulations and adequate market-based incentives may lower the costs of supplying pesticides, but at the same time can increase the tendency for ineffective, inefficient and non-sustainable crop protection. For a system-wide programme on IPM to make a significant contribution, the policy and institutional environment of global crop protection cannot be ignored (Settle and Garba 2011).

The European Commission Directive 2009/128/EC on the sustainable use of pesticides establishes a framework to achieve a sustainable use of pesticides by reducing the risks and impacts of pesticide use on human health and the environment and promoting the use of IPM and alternative approaches or techniques such as non-chemical alternatives to pesticides. Other provisions include compulsory testing of application equipment, training and certification of all professional users, distributors and advisors; a ban (subject to derogations) on aerial spraying; special measures to protect the aquatic environment, public spaces and conservation areas; minimizing the risks to human health and the environment through handling, storage and disposal (Official Journal of the European Union 2009).

6 Challenges of the Global Pesticide Market

Globalisation is affecting pest management on and off the farm. Reduction in trade barriers increases competitive pressures and provides extra incentives for farmers to reduce costs and increase crop yields. Liberalisation of input markets, often labelled as successful market reform, can lead to inefficient pesticide use and high external costs (FAO 2009). Other forms of trade barriers create disincentives for adopting new technologies such as the reluctance of the EU to accept genetically modified organisms.

It is important to point out that it is not only the big multinationals that are important players in pesticide policy but also the many new companies in developing countries who produce generics. A trend in agrichemical industry is the movement of many chemical pesticides off patent. As these chemicals become generic pesticides, manufacturers lose their monopolies on them. Overall, generic companies make up about 30 % of total sales (McDougall 2010). Rising sales of generic pesticides, especially in countries in Africa and Latin America but also in some Asian countries, is often facilitated by weak regulatory control and the lack of an IPM oriented national policy framework countries (FAO 2009).

Around 30 % of pesticides marketed in developing countries with an estimated market value of USD 900 million annually do not meet internationally accepted quality standards. They are posing a serious threat to human health and the environment. Such pesticides often contribute to the accumulation of obsolete pesticide stocks in developing countries (FAO 2009). Another negative economic consequence of a higher use of pesticides in developing countries is the loss of export opportunities for developing countries especially with horticultural crops as the developed countries are tightening maximum residue levels (FAO/WHO 2010).

Sustainable, IPM based on biological control is urgently needed, opening increasing possibilities for biopesticides. Their beneficial features include that they are often very specific, they are "inherently less toxic than conventional pesticides" compatible with other control agents, leave little or no residue, are relatively inexpensive to develop, and support the action of natural enemies in ecologically-based IPM.

As a result of the various merger and acquisition that have taken place, the agrochemical sector is relatively highly consolidated. An increasing number of merger and acquisition transactions have been targeted at strengthening the respective product portfolios of the purchasing company through the acquisition of a particular agrochemical product or product range. While product acquisitions have always been a feature of the agrochemical industry, the overall level of this type of merger and acquisition activity has increased significantly in the last 10 years (Mc Dougall 2010).

The total cost of agrochemical research and development expenditure in 2007 for 14 leading companies was 6.7 % of their agrochemical sales. Over the next 5 years it is expected that herbicides will lead market growth while the insecticides sector is likely to suffer further generic pressure and the fungicide sector is expected to grow relatively modestly with increases generated from a further expansion of the seed treatment sector. The GM crop sector is also expected to continue to move increasingly toward multiple trait stacked gene varieties, in both established and developing markets (McDougall 2010).

Industrial leaders expect that advances in genomics will lead researchers to the precise location and sequence of genes that contain valuable input and output traits. A shift in research and development resources from input to output traits probably would have a large impact on the future of plant protection. Will the cycle of innovation on the input side continue? Because of the high investment required for development of chemical pesticides and transgenic crops, will large agrichemical and life-science firms focus primarily on crops with large markets? Whether companies will develop pesticides and input traits for minor use crops remains an open question. These are the main questions research and development of plant protection is facing at present.

7 Conclusion

The main reasons why world food supply is tightening are population growth, accelerated urbanization and motorization, changes in diets and climate change. Furthermore, agricultural land is used to produce more bioenergy and other bio-based commodities. To meet the increasing world food demand the necessary production growth will to a large extent have to be met by a rise in the productivity of the land already being farmed today. However, this will be difficult to accomplish as global agricultural productivity growth has been in decline since the Green Revolution. In addition to the reduction of waste along the whole food chain priority has to be given to effective crop protection measures to cut further crop losses to pests.

Cost-benefit analyses are important tools for informing policy decisions regarding use of chemical pesticides. The impacts of pesticides on the economy, environment and public health are measured in monetary terms. However, there are many uncertainties in measuring the full array of benefits and costs of pesticide use. Making wise tradeoffs to achieve a fair balance between the risks that a community bears and the benefits that it receives is one of the most difficult challenges for policy-makers.

Chemical pesticides will continue to play a role in pest management because environmental compatibility of products is increasing and competitive alternatives are not universally available. Pesticides provide economic benefits to producers and by extension to consumers. One of the major benefits of pesticides is protection of crop quality and yield. Pesticides can prevent large crop losses, thus raising agricultural output and farm income. The benefits of pesticide use are high relative to risks. Non-target effects of exposure of humans and the environment to pesticide residues are a continuing concern. Side effects of pesticides can be reduced by improving application technologies. Innovations in pesticide-delivery systems in plants promise to reduce adverse environmental impacts even further but are not expected to eliminate them. The correct use of pesticides can deliver significant socio-economic and environmental benefits.

Genetically engineered organisms that reduce pest pressure constitute a “new generation” of pest-management tools. This change in production system has made additional positive economic contributions to farmers and delivered important environmental benefits. But genetically engineered crops that express a control chemical can exert strong selection for resistance in pests. Thus, the use of transgenic crops will even increase the need for effective resistance-management programmes.

Many biocontrol agents are not considered acceptable by farmers because they are evaluated for their immediate impact on pests. Evaluation of the effectiveness of biocontrol agents should involve consideration of long-term impacts rather than only short-term yield, as is typically done for conventional practices. The global sale of biopesticides is very small compared to the pesticide market. However, the market share of biopesticides is growing faster than that of conventional chemicals. Finding continuously new cost-effective and environmentally sound solutions to improve control of pest and disease problems is critical to improving the health and livelihoods of the poor. The need for a more holistic and modernised IPM approach in low-income countries is now more important than ever before.

Total investment in pest management and the rate of new discoveries should be increased to address biological, biochemical and chemical research that can be applied to ecologically based pest management. There is underinvestment from a social perspective in private-sector research because companies will aim to maximise only what is called suppliers' surplus. Transmission of knowledge in the past was the responsibility mostly of the public sector, but it has become more privatised. The public sector must act on its responsibility to provide quality education to ensure well-informed decision-making in both the private and public sectors by emphasising systems-based interdisciplinary research.

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Farmland Birds and Arable Farming, a Meta-Analysis

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Abstract Declines in farmland bird populations have been principally attributed to the intensification of agriculture. In response, agri-environmental schemes and organic farming have been introduced with the aim of making farmland better able to support wildlife populations. These "bird-friendly" agricultural practices include using more diverse crop rotations, stopping the use of pesticides, and creating more heterogeneous landscapes and are expected to create more food resources and nesting habitats for birds. Many studies have been published that evaluate the success or failure of agricultural practices to increase bird abundance. While many studies have found that most organic farming practices are beneficial to birds, other studies have found that some organic farming practices, such as using increased tillage passes, are not beneficial to birds. We conducted a search of the literature and used a meta-analysis approach to analyze the relationship between farming practices and bird populations. We first tested whether organic

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agriculture is more favorable to farmland birds of Europe and North America compared to conventional agriculture. We used data from 16 experiments and six publications that fulfilled fixed criteria for inclusion in the meta-analysis. We found that organic agriculture had a global positive effect on bird abundance compared to conventional agriculture. However, this effect was significant in only five out of the 16 site-year combinations tested. We also found that the effects varied with the bird species. Ten out of the thirty six species tested show a significant higher abundance value in organic agriculture. When the ratio was significantly different from zero, the abundance was 1.5–18 times higher in organic systems in comparison to conventional systems.

We also tested the effect of crop type on the territory abundance of the most studied species in the literature, the skylark (*Alauda arvensis*). Using data from six publications, we found two-times more skylark territories in set-aside and legume fields during the breeding season than in other crop types. One of the problems we encountered in our meta-analysis was that many different bird metrics were used in the studies, and these data were often reported without standard deviations or other measures of variability. We describe problems encountered with the data found in the literature and provide recommendations to prevent these problems.

Keywords Agriculture • Organic farming • Conventional farming • Bird abundance • Skylark • Meta-analysis

1 Introduction

Declines in bird populations associated with farmland habitat have been recorded during recent decades and have been principally attributed to changes in farming practices and homogenization of agricultural landscapes (Benton et al. 2003; Donald et al. 2006). These changes include introducing simplified crop rotations, increasing the use of chemical inputs, and removing semi-natural landscape elements for field enlargement. The replacement of spring cereals with winter cereals in crop rotations has been found to decrease the prevalence of winter stubble fields, which provide winter food resources for birds (Robinson and Sutherland 2002; Eraud and Corda 2004; Newton 2004; Gillings et al. 2005). Studies have also found that the use of pesticides can reduce the abundance of weeds and invertebrates important to the diet of birds (Rands 1986; Wilson et al. 1999; Boatman et al. 2004; Newton 2004).

In recognition of the often negative impact of modern agriculture on biodiversity, agri-environmental schemes and organic farming have been implemented with the goal of improving the ability of farmland to support wildlife species (Kleijn and Sutherland 2003; Vickery et al. 2004). Organic systems do not use synthetic pesticides, herbicides or fertilizers, and they also often have more diverse crop rotations than conventional systems (Piha et al. 2007). Current literature identifies two main reasons for the positive effect of organic farming on birds. First, the elimination of chemical inputs may provide more food resources, plant and invertebrate populations are expected to be more numerous and able to support larger bird populations (Boatman et al. 2004; Newton 2004). Second, organic systems generally provide more heterogeneous landscapes than conventional farms (McKenzie and Whittingham 2009). Organic farms often use a greater diversity of crop rotations and maintain non-crop elements within the farm, such as hedgerows (Fuller et al. 2005; McKenzie and Whittingham 2009; Norton et al. 2009). This diversity of landscape elements can provide for the different habitat needs of a greater range of bird species (Benton et al. 2003).

A considerable amount of published literature has assessed these relationships between farming practices and birds. All bird species are not equally studied, and skylark (*Alauda arvensis*) is by far the most studied species. Some studies examine bird preferences for different crop types, while others examine the success of different agri-environmental schemes in increasing bird abundance. However, these studies often present contrasting results or are inconclusive (Peach et al. 2001; Bradbury et al. 2004; Bro et al. 2004; Field et al. 2007; Roth et al. 2008). In a meta-analysis, Bengtsson et al. (2005) found an overall small increase in bird species richness and abundance in organic compared to conventional farming systems during the breeding season. A qualitative review concluded that organic farming generally supports greater bird abundance than conventional farming, but this trend varied across studies and bird species (Hole et al. 2005). Furthermore, some studies have found that organic farming may not be beneficial to all bird species. For instance, organic farms can provide less over-winter stubble fields than conventional farms (Chamberlain et al. 2010), and can function as ecological traps for birds if organic agriculture relies on increased tillage passes to control weeds, which can disturb or destroy bird nests (Beecher et al. 2002; Kragten and de Snoo 2007). To our knowledge, a more recent meta-analysis reviewing literature published after 2002 that examines birds' response to organic farming is not available.

In light of these conflicting conclusions, we propose to perform an updated examination of the published data using a meta-analysis approach. Meta-analysis is a quantitative review that combines data from different studies to summarize findings, and it has been increasingly used in ecological research (Arnqvist and Wooster 1995; Gurevitch and Hedges 1999). Our goal was to analyze the data available on the relationship between farming practices and farmland bird populations of Europe and North America and examine what conclusions can be made using meta-analysis techniques. First, focusing on a large set of farmland bird species, we tested whether organic agriculture is more favorable to birds compared to conventional agriculture, considering species and site-year effects. Second, focusing on the most studied species in the literature (skylark), we examined if skylark territory abundance differs among crop types. Finally, we propose recommendations for future publications to improve the quality of data reported on this subject.

2 Materials and Methods

2.1 Literature Search

We conducted a search of the literature published before February 2010 using ISI Web of Science, CAB Abstracts and Zoological Records. The objective was to find peer-reviewed studies containing quantitative information on farmland bird species of Europe and North America in arable agriculture.

We developed a series of queries to search the literature (Table 1). The first of these queries contained six simple keywords related to birds as well as the names of 56 bird species and 20 bird families considered as farmland birds in Europe. The next two queries contained 20 cropland-related keywords and 30 habitat-related keywords. In order to be included in the study, articles needed to contain one keyword from the first bird-related queries, plus a keyword from each of the cropland- and habitat-related queries. In addition, selected articles could not contain one of the 89 exclusion terms that made up the remaining queries. Finally, a total of 17 additional exclusion words were used to remove articles from non-target countries.

We only considered studies published in English that met the following two criteria:

1. A measure of bird abundance, productivity or species richness was given (not a percentage or results of a model prediction), and
2. The quantitative bird metric was directly related to an arable farming practice, system, or crop type.

We found 66 articles with data that fulfilled these criteria (Table 2). Of these articles, we further searched for articles that explicitly compared the impact of both organic and conventional systems on farmland birds and for which standard deviations or standard errors on the measurement of bird abundance are given (Table 3). We found six articles with data that fulfilled these criteria for inclusion in our first meta-analysis (Table 4). We further searched for articles that examined the crop type preferences of the skylark and for which standard deviations or standard errors on the measurement of bird abundance are given. We found six articles with data that fulfilled these criteria for inclusion in our second meta-analysis.

2.2 Data Extraction

Data from these 66 publications were entered into a relational database. These data used different metrics to characterize bird presence (Table 5). We also recorded information on the month(s), season(s), and year(s) when the studies took place. Data were collected from the text, data tables and digitized figures of the articles.

Table 1 Queries used to search the primary literature

Bird inclusion keywords:	avian OR avifaun* OR bird* OR passerine* OR songbird* OR sparrow*
	“Acrocephalus palustris” OR “Alauda arvensis” OR “Anthus campestris” OR “Anthus pratensis” OR “Apus apus” OR “Calandrella brachydactyla” OR “Carduelis cannabina” OR “Carduelis carduelis” OR “Carduelis chloris” OR “Chloris chloris” OR “Cettia cetti” OR “Ciconia ciconia” OR “Cisticola juncidis” OR “Corvus corone” OR “Corvus frugilegus” OR “Corvus monedula” OR “Delichon urbic*” OR “Emberiza calandra” OR “Emberiza cirlus” OR “Emberiza citrinella” OR “Emberiza hortulana” OR “Falco tinnunculus” OR “Galerida cristata” OR “Galerida theklae” OR “Gallinago gallinago” OR “Hippolais polyglotta” OR “Hirundo rustica” OR “Lanius collurio” OR “Lanius senator” OR “Limosa limosa” OR “Locustella naevia” OR “Lullula arborea” OR “Luscinia megarhynchos” OR “Melanocorypha calandra” OR “Merops apiaster” OR “Miliaria calandra” OR “Motacilla alba” OR “Motacilla flava” OR “Oenanthe hispanica” OR “Oenanthe oenanthe” OR “Passer domesticus” OR “Passer montanus” OR “Perdix perdix” OR “Petronia petronia” OR “Pica pica” OR “Saxicola rubetra” OR “Saxicola torquat*” OR “Serinus serinus” OR “Streptopelia turtur” OR “Sturnus unicolor” OR “Sturnus vulgaris” OR “Sylvia communis” OR “Sylvia curruca” OR “Turdus pilaris” OR “Upupa epops” OR “Vanellus vanellus”
	alaudidae OR apodidae OR charadriidae OR ciconiidae OR col?mbidae OR corvidae OR emberizidae OR fringillidae OR falconidae OR hirundinidae OR laniidae OR meropidae OR motacillidae OR passeridae OR phasianidae OR scolopacidae OR sturnidae sylviidae OR turdidae OR upupidae
Cropland inclusion keywords:	agriculture* OR “agro-ecosystem$” OR agroecosystem$ OR “agro-system$” OR agrosystem$ OR anthropogenic OR arable OR conventional OR crop* OR cultivated OR cultivation$ OR cultur* OR farm* OR “field use” OR “land-use” OR “land use” OR landuse OR lowland$ OR organic OR “set-aside$” OR upland$
Habitat inclusion keywords:	“agr?-environment*” OR “agricultural intensification” OR “agricultural management$” OR availab* OR diet OR diversity OR enhance* OR factor$ OR feature$ OR feed* OR food$ OR forag* OR fragmentation OR granivor* OR habitat$ OR heterogene* OR homogene* OR insectivor* OR invertebrate$ OR landscape$ OR mosaic$ OR occupancy OR prefer* OR quality OR requirement$ OR resource$ OR seed$ OR selection$ OR suitab* OR weed*
Exclusion keywords:	alp* OR amazon* OR “animal welfare$” OR antibiotic$ OR “aquatic bird$” OR bacillus OR “boreal forest$” OR brain$ OR campylobacter OR chicken$ OR “climate change$” OR “climat* warming” OR collision$ OR “conventional cage$” OR cormorant$ OR “cotton crop$” OR “crop damage” OR deer$ OR desert$ OR disease OR DNA OR “domestic fowl” OR duck$ OR eagle$ OR embryo* OR emu$ OR enzyme$ OR “escherichia coli” OR estuar* OR eucalypt* OR “exotic bird$” OR fish OR “forest habitat$” OR frog$ OR geese OR goose OR hoatzin$ OR hormone$ OR influenza OR “japanese quail” OR lung$ OR marine OR marsupial$ OR medicine OR mitochondri* OR mountain* OR “montane habitat$” OR mussel$ OR neotropic* OR neural OR neuron* OR ontogen* OR osteoclast$ OR ostrich* OR “organic acid$” OR “organic condition$” OR pacific$ OR palm$ OR parasit* OR pine OR plantation$ OR poultry OR “rain-forest$” OR ratite$ OR retin* OR salmon* OR salmonell* OR seabird$ OR seismic OR skeleton$ OR snake$ OR subalp* OR subtropical OR sucrose OR syllable$ OR tropic* OR tuberculosis OR turkey$ OR urban* OR vaccin* OR virus OR waterbird$ OR waterfowl$
Country exclusion keywords:	Africa OR Argentina OR Brazil OR Burma OR Cambodia OR China OR Columbia OR Ecuador OR India OR Indonesia OR Japan OR Kenya OR Malaysia OR Nepal OR Nigeria OR Pakistan OR Taiwan

Asterisks are used as wildcard terms to represent many possible terms

Table 2 List of the 66 publications used in the meta-analysis

Basore NS, Best LB, Wooley JB Jr (1986) Bird nesting in Iowa no-tillage and tilled cropland. J Wildl Manag 50:19–28

Beecher NA, Johnson RJ, Brandle JR, Case RM, Young LJ (2002) Agroecology of birds in organic and nonorganic farmland. Conserv Biol 16:1620–1631

Bellamy PE, Croxton PJ, Heard MS, Hinsley SA, Hulmes L, Hulmes S, Nuttall P, Pywell RF, Rothery P (2009) The impact of growing miscanthus for biomass on farmland bird populations. Biomass Bioenerg 33:191–199. doi:10.1016/j.biombioe.2008.07.001

Berg A, Lindberg T, Kallebrink KG (1992) Hatching succes of lapwings on farmland: differences between habitats and colonies of different sizes. J Anim Ecol 61:469–476

Bracken F, Bolger T (2006) Effects of set-aside management on birds breeding in lowland Ireland. Agric Ecosyst Environ 117:178–184. doi:10.1016/j.agee.2006.03.032

Bradbury RB, Browne SJ, Stevens DK, Aebischer NJ (2004) Five-year evaluation of the impact of the arable stewardship pilot scheme on birds. Ibis 146:171–180

Bradbury RB, Kyrkos A, Morris AJ, Clark SC, Perkins AJ, Wilson JD (2000) Habitat associations and breeding success of yellowhammers on lowland farmland. J Appl Ecol 37:789–805

Brickle NW, Harper DGC (2002) Agricultural intensification and the timing of breeding of Corn Buntings *Miliaria calandra*. Bird Stud 49:219–228

Brickle NW, Peach WJ (2004) The breeding ecology of Reed Buntings *Emberiza schoeniclus* in farmland and wetland habitats in lowland England. Ibis 146:69–77

Bro E, Mayot P, Corda E, Reitz F (2004) Impact of habitat management on grey partridge populations: assessing wildlife cover using a multisite BACI experiment. J Appl Ecol 41:846–857

Browne S, Vickery J, Chamberlain D (2000) Densities and population estimates of breeding Skylarks *Alauda arvensis* in Britain in 1997. Bird Stud 47:52–65

Butler SJ, Bradbury RB, Whittingham MJ (2005) Stubble height affects the use of stubble fields by farmland birds. J Appl Ecol 42:469–476. doi:10.1111/j.1365-2664.2005.01027.x

Cederbaum SB, Carroll JP, Cooper RJ (2004) Effects of alternative cotton agriculture on avian and arthropod populations. Conserv Biol 18:1272–1282

Chamberlain DE, Freeman SN, Vickery JA (2007) The effects of GMHT crops on bird abundance in arable fields in the UK. Agric Ecosyst Environ 118:350–356. doi:10.1016/j.agee.2006.05.012

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Chamberlain DE, Wilson JD, Fuller RJ (1999) A comparison of bird populations on organic and conventional farm systems in southern Britain. Biol Conserv 88:307–320

Delgado A, Moreira F (2000) Bird assemblages of an Iberian cereal steppe. Agric Ecosyst Environ 78:65–76

Delgado A, Moreira F (2002) Do wheat, barley and oats provide similar habitat and food resources for birds in cereal steppes? Agric Ecosyst Environ 93:441–446. doi:10.1016/s0167-8809(02)00095-6

Donald PF, Evans AD, Buckingham DL, Muirhead LB, Wilson JD (2001) Factors affecting the territory distribution of Skylarks *Alauda arvensis* breeding on lowland farmland. Bird Stud 48:271–278

Donald PF, Evans AD, Muirhead LB, Buckingham DL, Kirby WB, Schmitt SIA (2002) Survival rates, causes of failure and productivity of Skylark *Alauda arvensis* nests on lowland farmland. Ibis 144:652–664

East M (1988) Crop selection, feeding skills and risks taken by adult and juvenile rooks *Corvus frugilegus*. Ibis 130:294–299

Eraud C, Boutin JM (2002) Density and productivity of breeding Skylarks Alauda arvensis in relation to crop type on agricultural lands in western France. Bird Stud 49:287–296

Eraud C, Corda E (2004) Nocturnal field use by wintering skylark *Alauda arvensis* on intensive farmlands. Rev Ecol-Terre Vie 59:581–589

Evans KL, Wilson JD, Bradbury RB (2007) Effects of crop type and aerial invertebrate abundance on foraging barn swallows *Hirundo rustica*. Agric Ecosyst Environ 122:267–273. doi:10.1016/j.agee.2007.01.015

Field RH, Benke S, Badonyi K, Bradbury RB (2007) Influence of conservation tillage on winter bird use of arable fields in Hungary. Agric Ecosyst Environ 120:399–404. doi:10.1016/j.agee.2006.10.014

Freemark KE, Kirk DA (2001) Birds on organic and conventional farms in Ontario: partitioning effects of habitat and practices on species composition and abundance. Biol Conserv 101:337–350

Fuller RJ, Lloyd D (1981) The distribution and habitats of wintering golden plovers in Britain, 1977–1978. J Bird Stud 28:169–185

Galbraith H (1988) Effects of agriculture on the breeding ecology of lapwings *Vanellus vanellus*. J Appl Ecol 25:487–503

Galbraith H (1989) Arrival and habitat use by lapwings *Vanellus vanellus* in the early breeding season. Ibis 131:377–388

Gillings S, Fuller RJ (2001) Habitat selection by Skylarks *Alauda arvensis* wintering in Britain in 1997/98. Bird Stud 48:293–307

Gilroy JJ, Anderson GQA, Grice PV, Vickery JA, Watts PN, Sutherland WJ (2009) Foraging habitat selection, diet and nestling condition in Yellow Wagtails *Motacilla flava* breeding on arable farmland. Bird Stud 56:221–232

Gruar D, Barritt D, Peach WJ (2006) Summer utilization of oilseed rape by reed buntings *Emberiza schoeniclus* and other farmland birds. Bird Stud 53:47–54

Hancock MH, Wilson JD (2003) Winter habitat associations of seed-eating passerines on Scottish farmland. Bird Stud 50:116–130

Henderson IG, Ravenscroft N, Smith G, Holloway S (2009) Effects of crop diversification and low pesticide inputs on bird populations on arable land. Agric Ecosyst Environ 129:149–156. doi:10.1016/j.agee.2008.08.014

Henderson IG, Vickery JA, Carter N (2004) The use of winter bird crops by farmland birds in lowland England. Biol Conserv 118:21–32. doi:10.1016/j.biocon.2003.06.003

Herzon I, Aunins A, Elts J, Preiksa Z (2008) Intensity of agricultural land-use and farmland birds in the Baltic States. Agric Ecosyst Environ 125:93–100. doi:10.1016/j.agee.2007.11.008

Kasprzykowski Z (2003) Habitat preferences of foraging Rooks *Corvus frugilegus* during the breeding period in the agricultural landscape of eastern Poland. Acta Ornithol 38:27–31

(continued)

Table 2 (continued)

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Kragten S, de Snoo GR (2008) Field-breeding birds on organic and conventional arable farms in the Netherlands. Agric Ecosyst Environ 126:270–274. doi:10.1016/j.agee.2008.02.006

Kragten S, Trimbos KB, de Snoo GR (2008) Breeding skylarks (*Alauda arvensis*) on organic and conventional arable farms in The Netherlands. Agric Ecosyst Environ 126:163–167. doi:10.1016/j.agee.2008.01.021

Laiolo P (2005) Spatial and seasonal patterns of bird communities in Italian agroecosystems. Conserv Biol 19:1547–1556. doi:10.1111/j.1523-1739.2005.00207.x

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Nagy S, Nagy K, Szep T (2009) Potential impact of EU accession on common farmland bird populations in Hungary. Acta Ornithol 44:37–44. doi:10.3161/000164509x464867

Orlowski G (2005) Habitat use by breeding and wintering reed bunting *Emberiza schoeniclus* L. in farmland of Lower Silesia (SW Poland). Pol J Ecol 53:243–254

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Parish DMB, Sotherton NW (2004) Game crops and threatened farmland songbirds in Scotland: a step towards halting population declines? Bird Stud 51:107–112

Parish T, Lakhani KH, Sparks TH (1995) Modeling the relationship between bird population variables and hedgerow, and other field margin attributes. 2 Abundance of individual species and of group of similar species. J Appl Ecol 32:362–371

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Wakeham-Dawson A, Aebischer NJ (1998) Factors determining winter densities of birds on Environmentally Sensitive Area arable reversion grassland in southern England, with special reference to skylarks (*Alauda arvensis*). Agric Ecosyst Environ 70:189–201

Wakeham-Dawson A, Szoszkiewicz K, Stern K, Aebischer NJ (1998) Breeding skylarks *Alauda arvensis* on environmentally sensitive area arable reversion grass in southern England: survey-based and experimental determination of density. J Appl Ecol 35:635–648

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Wolnicki K, Lesinski G, Rembialkowska E (2009) Birds inhabiting organic and conventional farms in central Poland. Acta Zool Crac Ser A-Vertebr 52A:1–10

Table 3 Informations about the 66 studies used in the analysis of the relationship between birds and arable farmland practices

Citation	Study location	Bird species concerned	Season	Study type comparison
Basore et al. 1986	USA	Multiple species	Reproductive	No tillage versus conventional
Beecher et al. 2002[a]	USA	Multiple species	Reproductive	Organic versus conventional
Bellamy et al. 2009[b]	UK	Multiple species	Reproductive and winter	Miscanthus versus winter wheat
Berg et al. 1992	Sweden	Northern lapwing	Reproductive	Multiple habitats
Bracken and Bolger 2006	Ireland	Multiple species	Reproductive	Multiple habitats
Bradbury et al. 2000	UK	Yellowhammer	Reproductive	Organic versus conventional
Bradbury et al. 2004	UK	Multiple species	Winter	Agri-environmental schemes versus conventional
Brickle and Harper 2002	UK	Corn bunting	Reproductive	Multiple habitats
Brickle and Peach 2004	UK	Reed bunting	Reproductive	Multiple habitats
Bro et al. 2004	France	Grey partridge	Reproductive	Cover-strip fields versus conventional
Browne et al. 2000[b]	UK	Skylark	Reproductive	Multiple habitats
Butler et al. 2005	UK	Multiple species	Winter	Shorter stubbles versus conventional
Cederbaum et al. 2004	USA	Multiple species	Reproductive and winter	Conservation tillage and strip-cover versus conventional
Chamberlain et al. 1999[a]	UK	Multiple species	Reproductive and winter	Organic versus conventional
Chamberlain et al. 2007	UK	Multiple species	Reproductive and winter	Genetically-modified versus conventional
Chamberlain et al. 2010	UK	Multiple species	Winter	Organic versus conventional
Delgado and Moreira 2000	Portugal	Multiple species	Reproductive and winter	Multiple habitats
Delgado and Moreira 2002	Portugal	Multiple species	Reproductive and winter	Multiple habitats
Donald et al. 2001	UK	Skylark	Reproductive	Multiple habitats
Donald et al. 2002	UK	Skylark	Reproductive	Multiple habitats
East 1988	UK	Rook	Reproductive	Multiple habitats
Eraud and Boutin 2002[b]	France	Skylark	Reproductive	Multiple habitats
Eraud and Corda 2004	France	Skylark	Winter	Multiple habitats

Evans et al. 2007	UK	Barn swallow	Reproductive	Multiple habitats
Field et al. 2007	Hungary	Multiple species	Winter	Conservation tillage versus conventional
Freemark and Kirk 2001	Canada	Multiple species	Reproductive	Organic versus conventional
Fuller and Lloyd 1981	UK	Golden plover	Winter	Multiple habitats
Galbraith 1988	UK	Northern lapwing	Reproductive	Multiple habitats
Galbraith 1989	UK	Northern lapwing	Reproductive	Multiple habitats
Gillings and Fuller 2001	UK	Skylark	Winter	Multiple habitats
Gilroy et al. 2009	UK	Yellow wagtail	Reproductive	Multiple habitats
Gruar et al. 2006	UK	Reed bunting	Reproductive	Multiple habitats
Hancock and Wilson 2003	UK	Multiple species	Winter	Multiple habitats
Henderson et al. 2004	UK	Multiple species	Winter	Wildlife cover crops versus conventional
Henderson et al. 2009	UK	Multiple species	Reproductive and winter	Multiple habitats
Herzon et al. 2008	Lithuania, Latvia, Estonia	Multiple species	Reproductive	Extensive versus conventional
Kasprzykowski 2003	Poland	Rook	Reproductive	Multiple habitats
Kleijn et al. 2006[a]	Germany, Spain	Multiple species	Reproductive	Agri-environmental schemes versus conventional
Kragten and de Snoo 2007[a]	Netherlands	Northern lapwing	Reproductive	Organic versus conventional
Kragten and de Snoo 2008[a, b]	Netherlands	Multiple species	Reproductive	Organic versus conventional
Kragten et al. 2008	Netherlands	Skylark	Reproductive	Organic versus conventional
Laiolo 2005	Italy	Multiple species	Reproductive and winter	Multiple habitats
Mason and Macdonald 2000[b]	UK	Multiple species	Reproductive	Multiple habitats
Nagy et al. 2009	Hungary	Multiple species	Reproductive	Multiple habitats
Orlowski 2005	Poland	Reed bunting	Winter	Multiple habitats
Orlowski 2006	Poland	Multiple species	Winter	Multiple habitats
Panek 2002;	Poland	Grey partridge	Reproductive	Multiple habitats
Parish and Sotherton 2004	UK	Multiple species	Winter	Wildlife cover crops versus conventional

(continued)

Table 3 (continued)

Citation	Study location	Bird species concerned	Season	Study type comparison
Parish et al. 1995	UK	Multiple species	Winter	Multiple habitats
Perkins et al. 2008	UK	Multiple species	Winter	Wildlife cover crops versus conventional
Piha et al. 2007[a]	Finland	Multiple species	Reproductive	Organic versus conventional
Poulsen et al. 1998[b]	UK	Skylark	Reproductive	Multiple habitats
Rands 1985	UK	Grey partridge	Reproductive	Herbicide sprayed versus unsprayed
Rands 1986	UK	Multiple species	Reproductive	Herbicide sprayed versus unsprayed
Rodgers 2002	USA	Common pheasant	Winter	Herbicide sprayed or tilled versus unsprayed and untilled
Roth et al. 2008	Switzerland	Multiple species	Reproductive	Agri-environmental schemes versus conventional
Sage et al. 2005	UK	Multiple species	Reproductive and winter	Wildlife cover crops versus conventional
Snyder 1984	USA	Common pheasant	Reproductive	Multiple habitats
Sotherton 1990	UK	Multiple species	Reproductive	Unsprayed crop margins versus conventional
Stoate et al. 2000	Portugal	Corn bunting	Reproductive	Multiple habitats
Suarez et al. 2004	Spain	Multiple species	Winter	Multiple habitats
Wakeham-Dawson and Aebischer 1998	UK	Multiple species	Winter	Multiple habitats
Wakeham-Dawson et al. 1998	UK	Skylark	Reproductive	Multiple habitats
Wilson et al. 1996	UK	Multiple species	Winter	Multiple habitats
Wilson et al. 2001	UK	Northern lapwing	Reproductive	Multiple habitats
Wolnicki et al. 2009	Poland	Multiple species	Reproductive	Organic versus conventional

[a] Used in the analysis of organic versus conventional farming

[b] Used in the analysis of skylark territory abundance and crop type

Table 4 Data extracted from the six articles included in the meta-analysis of organic versus conventional farming

Citation	Study location	Bird latin name	Bird common name	Bird metric measured	Crop types examined	Scale of study
Beecher et al. (2002)	USA	*Carpodacus mexicanus*	House finch	Mean bird abundance per 10 ha of transect	Maize	Field
		Charadrius vociferus	Killdeer			
		Chondestes grammacus	Lark sparrow			
		Cyanocitta cristata	Blue jay			
		Eremophila alpestris	Shore lark			
		Hirundo rustica	Barn swallow			
		Passer domesticus	House sparrow			
		Petrochelidon pyrrhonota	Cliff swallow			
		Spizella passerina	Field sparrow			
		Spinus tristis	American goldfinch			
		Stelgidopteryx serripennis	Northern rough-winged swallow			
		Turdus migratorius	American robin			
		Zenaida macroura	Mourning dove			
Chamberlain et al. (1999)	UK	*Alauda arvensis*	Skylark	Mean bird abundance per 10 ha	Mostly winter and spring cereals	Farm
		Alectoris rufa	Red-legged partridge			
		Carduelis cannabina	Linnet			
		Carduelis carduelis	Goldfinch			
		Carduelis chloris	Greenfinch			
		Columba oenas	Stock pigeon			
		Columba palumbus	Common wood pigeon			
		Emberiza citrinella	Yellowhammer			
		Fringilla coelebs	Chaffinch			
		Perdix perdix	Grey partridge			
		Sturnus vulgaris	Common starling			
		Turdus iliacus	Redwing			

(continued)

Table 4 (continued)

Citation	Study location	Bird latin name	Bird common name	Bird metric measured	Crop types examined	Scale of study
		Turdus merula	Common blackbird			
		Turdus philomelos	Song thrush			
		Turdus pilaris	Fieldfare			
		Turdus viscivorus	Mistle thrush			
		Vanellus vanellus	Lapwing			
Kleijn et al. (2006)	Germany	Multiple species combined	Multiple species combined	Total abundance of bird territories per 12,5 ha	Cereal fields	Plot
Kragten and de Snoo (2007)	Netherlands	*Vanellus vanellus*	Lapwing	Mean nest abundance per 100 ha and daily survival probability	Mostly spring cereals, potatoes, onions; also carrots, sugar beet, beans, peas, and belgian endive	Farm
Kragten and de Snoo (2008)	Netherlands	*Alauda arvensis*	Skylark	mean bird territories per 100 ha	mostly spring cereals, potatoes, onions; also carrots, sugar beet,beans, peas, and belgian endive	farm
		Anthus pratensis	Meadow pipit			
		Charadrius hiaticula	Ringed plover			
		Coturnix coturnix	Common quail			
		Motacilla flava	Yellow wagtail			
		Vanellus vanellus	Lapwing			
Piha et al. (2007)	Finland	*Alauda arvensis*	Skylark	Mean bird territories per ha	Spring cereals, grasslands, set-asides and winter cereals	Plot
		Anthus pratensis	Meadow pipit			
		Emberiza hortulana	Ortolan bunting			
		Saxicola rubetra	Whinchat			
		Vanellus vanellus	Lapwing			

Table 5 Variables extracted from the 66 articles used in the meta-analysis

Variable	Definition	Units	Number of articles using variable	Number of data available	Number of data with a standard deviation or standard error
Daily nest survival probability	Probability that a nest will survive a single day	Unitless	5	30	20
Mean bird abundance	Average number of individual birds observed	Per field, 1 km^2, 1, 10 ha, 100 m radius, 200 m transect, 1 km transect, 10 ha transect	22	1,238	781
Mean brood size	Average number of chicks per nest	Individuals per nest	6	95	68
Mean flock size	Average number of individual birds observed together	Per crop type	1	7	7
Mean nest abundance	Average number of nests found	10, 100 ha	4	63	52
Mean species richness	Average number of bird species observed	Species per site, species per visit	4	25	13
Mean successful nest abundance	Average number of nests found that reached the chick stage	1, 100 ha	2	27	23
Mean territory abundance	Average number of bird territories observed	1 km^2, ha; 10, 100 ha	9	243	219
Mean young per adult	Average number of chicks born per adult bird	Chicks	1	24	0
Median bird abundance	Median number of individual birds observed	1 ha, 1 km transect	2	90	0
Median species richness	Median number of bird species observed	Species per site	1	2	0
Median territory abundance	Median number of bird territories observed	1, 10 ha	2	35	0
Total bird abundance	Total number of individual birds observed	Field, 12.5 ha	15	753	8

(continued)

Table 5 (continued)

Variable	Definition	Units	Number of articles using variable	Number of data available	Number of data with a standard deviation or standard error
Total flocks	Total number of bird flocks observed	Field	1	10	0
Total nest abundance	Total number of nests found	Field	15	115	0
Total plots	Total number of plots or fields where species was observed	Plot, field	1	74	0
Total species abundance	Total number of species observed	Field	1	6	0
Total successful nest abundance	Total number of nests found that reached the chick stage	Field	2	7	0
Total territory abundance	Total number of bird territories observed	field, 12.5, 100 ha	5	72	12
Crop system: conventional	Crop system is typical of the region or intensive	NA	43	967	471
Crop system: non-cropped	The area is grassland or set-aside	NA	33	556	205
Crop system: organic	Chemical inputs are prohibited	NA	13	290	191
Crop system: pilot scheme	The area is part of an agri-environmental scheme, including extensive cropping systems, planting winter bird crops, using conservation tillage, or not spraying portions of fields	NA	17	435	111
Crop system: unknown	Cropping system is undefined	NA	26	668	225
Crop type: bare ground	Area is bare or recently ploughed	NA	10	117	30
Crop type: brassicas	Crops include oilseed rape and other brassicas	NA	14	60	25
Crop type: grass	Area is grassland	NA	28	476	185
Crop type: legume	Legume crops, including bean, pea, lucerne and soybean	NA	8	48	22

Crop type: maize	Maize crops	NA	10	212	147
Crop type: misc crops	Miscellaneous crops including cotton, kale, linseed, miscanthus, quinoa and sunflower	NA	8	204	41
Crop type: root vegetable	Root vegetable including carrot, onions, potato, turnip	NA	10	98	42
Crop type: set-aside	Area is permanent or rotational set-aside (left fallow)	NA	15	52	13
Crop type: spring cereal	Cereals sown in the spring	NA	11	45	26
Crop type: stubble	Stubble of many different crop types	NA	15	232	34
Crop type: sugar beet	Sugar beet crops	NA	4	36	34
Crop type: unknown	Crop type contains many different crop types or is undefined	NA	35	888	411
Crop type: winter cereal	Cereals sown in the winter or autumn	NA	32	448	193
Season: reproductive	Data recorded during the breeding season or summer	NA	46	1,388	663
Season: winter	Data recorded during winter or autumn	NA	30	1,528	540

2.3 Meta-Analysis on Bird Preferences for Organic or Conventional Farming

We defined an experiment as a unique combination of site, year, and season. From our six articles that included data on farmland bird abundance and standard errors, we identified a total of 16 experiments (Table 6). Ten experiments included abundance data on many different farmland bird species, five had information on only one species and one experiment combined all species abundance data together.

We calculated response ratios R of the metric of bird abundance in organic systems A_O to the metric of bird abundance in conventional systems A_C for all experiments and all bird species ($R = A_O/A_C$). By using response ratios, we can compare data that use different metrics. A ratio of 1 indicates that organic farming systems did not have a different effect on bird presence compared to conventional systems. Next, we calculated log response ratios ($\log(R)$) to normalize the data for analysis and then followed the methods of Hedges et al. (1999) to calculate 95 % confidence intervals (CIs) for the response ratio. The difference between the two farming systems was significant if the 95 % CIs of the ratios did not overlap with zero.

Differences of log response ratios between bird species within an experiment were determined using a chi square test. We computed a mean effect size by averaging all the log response ratios of the different species and calculated the confidence interval of the mean effect size for each one of the 16 experiments.

We computed a mean effect size for 36 species for which standard errors were available in the 16 experiments. Mean effect size and the confidence interval of the mean effect size were performed by averaging all the log response ratios for each species.

2.4 Meta-Analysis on Skylark Crop-Type Preferences

Due to the limited quantity of data available per species, the analysis of the relationship between crop types and bird territory abundance was limited to the skylark. We tested generalized linear models and mixed models with Poisson distributions with/without a term for crop type and with/without a random site-year effect. Model fit was assessed using the Akaïke Information Criterion (AIC) (Akaike 1974); the model with the lowest AIC value was retained. Analysis was performed on data from the reproductive season. We omitted 12 data from the analysis where the crop type was unknown.

We performed all statistical analyses using R version 2.12.2 (R Development Core Team 2011). Tests used a significance level of $P < 0.05$.

Table 6 Mean log ratio and confidence interval (95 %) associated for each of the 16 experiments comparing organic versus conventional farming

Exp	Article	Year of bird survey	Period	Nbr. species	Ratio	Log ratio	Chi square test[a]
1	Chamberlain et al. (1999)	1992	Fall	15	1.93 (0.93, 3.97)	0.66 (−0.07, 1.38)	*
2	Chamberlain et al. (1999)	1992	Not defined	1	3.67 (1.21, 12.06)	1.3 (0.19, 2.49)	na
3	Chamberlain et al. (1999)	1992	Winter	16	1.46 (1.11, 1.93)	0.38 (0.1, 0.66)	ns
4	Chamberlain et al. (1999)	1993	Fall	16	1.00 (0.68, 1.38)	−0.03 (−0.39, 0.32)	ns
5	Chamberlain et al. (1999)	1993	Not defined	1	1.73 (0.81, 3.74)	0.55 (−0.21, 1.32)	na
6	Chamberlain et al. (1999)	1993	Winter	15	1.88 (1.07, 3.25)	0.63 (0.07, 1.18)	ns
7	Chamberlain et al. (1999)	1994	Not defined	1	1.00 (0.41, 2.41)	0.00 (−0.88, 0.88)	na
8	Beecher et al. (2002)	1995	Early summer	11	2.75 (1.36, 5.53)	1.01 (0.31, 1.71)	*
9	Beecher et al. (2002)	1995	Late summer	10	2.56 (1.26, 5.21)	0.94 (0.23, 1.65)	*
10	Piha et al. (2007)	2000	Spring	5	1.12 (0.80, 1.54)	0.11 (−0.22, 0.43)	ns
11	Piha et al. (2007)	2001	Spring	5	1.26 (0.87, 1.80)	0.23 (−0.14, 0.59)	ns
12	Kleijn et al. (2006)	2006	Breeding	Not def.	1.02 (0.67, 1.57)	0.02 (−0.40, 0.45)	na
13	Kragten and de Snoo (2008)	2004	Not defined	5	1.45 (0.78, 2.69)	0.37 (−0.25, 0.99)	*
14	Kragten and de Snoo (2008)	2005	Not defined	6	1.32 (0.83, 2.12)	0.28 (−0.19, 0.75)	*
15	Kragten and de Snoo (2008)	2005	Not defined	1	1.97 (0.88, 4.48)	0.68 (−0.13, 1.50)	na
16	Kragten and de Snoo (2008)	2006	Not defined	1	1.73 (0.76, 3.97)	0.55 (−0.27, 1.38)	na

Results of chi square tests (p=5 %) examining differences among species in the same experiment are provided for those experiments with more than one species. We defined an experiment as a unique combination of site, year, and season

[a] * significant at p=0.05; *ns* not significant, *na* not available

3 Results and Discussion

3.1 *Characteristics of the Data Extracted from the 66 Articles*

The 66 publications presented findings that came from eighteen different countries: Canada, United States and sixteen countries in Europe. Most studies, 36 in total, were done in the United Kingdom. Thirty publications presented data on only one species. We extracted 2,916 data on 116 different bird species. The species with the most data extracted was the skylark with 381 data and nine articles devoted to this species. The second most common species found in our analysis was the grey partridge (*Perdix perdix*) with 167 data extracted, and the third most common species was the northern lapwing (*Vanellus vanellus*) with 165 data extracted. We also extracted 285 data on total species richness or total species abundance.

Table 5 shows the diversity of bird metrics found in the studies. Most data (59 %) were a mean value of a metric of bird presence within a defined area, but 36 % used a total value of bird presence, generally in an undefined area. The most common metric recorded was mean bird abundance, with 1,238 data extracted. Total bird abundance was the second most common metric with 753 data extracted, followed by mean bird territories with 268 data extracted. Surprisingly, a minority (41 %) of the data included a standard deviation or standard error of the metric measured.

One third of the data concerned conventional or intensive farming systems. An additional 23 % of the data came from cropping systems that were undefined. Most articles (39 of the 66 publications) examined bird preferences for different crop types, generally in either conventional or undefined farming systems. Twelve articles compared organic farming systems with conventional systems, and 10 % of all data concerned organic systems. Seventeen publications examined a diversity of farming practices intended to increase bird abundance. These data on bird-friendly measures represented 15 % of the data extracted.

The majority of the publications examined bird preferences for different crop types. We sorted the data extracted into 13 categories of crop types (Table 5). When data were given for fields that contained multiple crop types, the crop type was listed as unknown. The two most common crop types were winter cereals and grasslands. We also frequently extracted data on maize crops and stubble fields. Other crop types were less commonly encountered.

3.2 *Meta-Analysis of Bird Preference for Organic or Conventional Farming*

For the first part of our meta-analysis, we expected organic agriculture to be more favorable to birds compared to conventional agriculture. The average log ratios ranged from –0.03 (experiment 4) to 1.01 (experiment 8) which correspond to a mean difference between organic and conventional farming from one to three birds. The mean effect sizes, or the average log ratios over species, were higher than zero

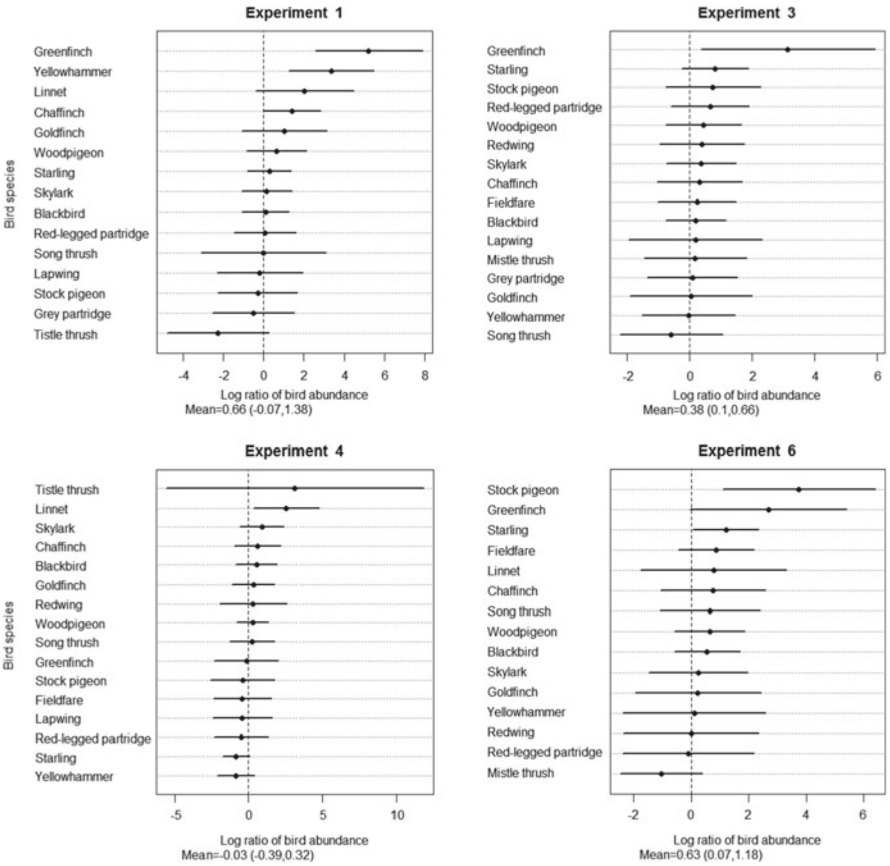

Fig. 1 Difference between organic and conventional farming on bird abundance. The difference between the two farming systems was assessed using the Log ratio of bird abundance between the organic system and conventional system. It was considered as significant if the 95 % CIs of the ratio did not overlap with zero. The error bars correspond to the 95 % confidence intervals. The log ratios were computed for a total of 16 experiments. We defined an experiment as a unique combination of site, year, and season whatever the number of species considered. Mean effect sizes (over bird species) and their 95 % confidence intervals are also indicated for each experiment

in all experiments except experiment 4 (Table 6). The 95 % confidence intervals were large and often overlapped the zero threshold. However, the log ratio confidence intervals did not overlap 0 in 5 out of 16 experiments, showing a significant positive effect of organic farming on bird abundance in these cases.

The experiments were conducted during different seasons, such as the breeding season or winter, but we did not detect any patterns relating season and mean effect size. For a given site, the mean effects of organic farming were variable, depending on the year, e.g., experiment 1 and 4, or on the season, e.g., experiment 4 and 6 (Table 6).

The high variability of the log ratio within an experiment can also be explained by differences in species response. As an example, Fig. 1 shows the log ratios for four of

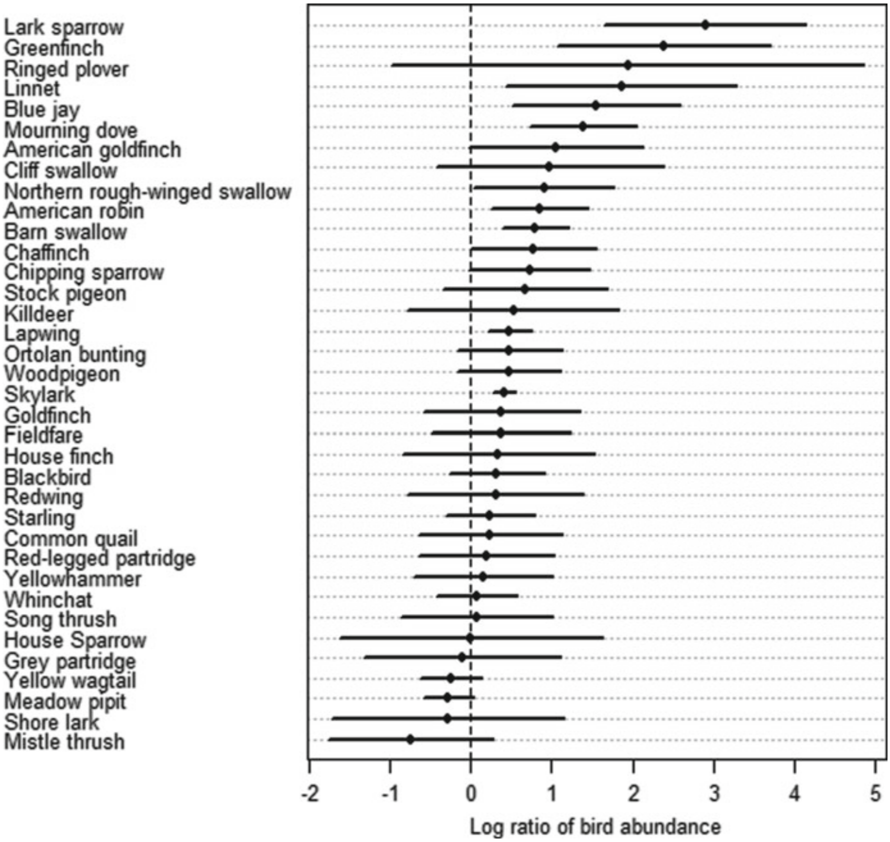

Fig. 2 Difference between organic and conventional farming for the different bird species used in the meta-analysis. The difference between the two farming systems was assessed using the Log ratio of species abundance between the organic system and conventional system. It was considered as significant if the 95 % CIs of the ratios did not overlap with zero. The error bars correspond to the 95 % confidence intervals. The log ratios were computed for a total of 36 species. Log ratios confidence intervals of 10 out of 36 species do not overlap zero, showing a significant positive effect of organic system on abundance

the ten experiments where data from several bird species were given. The Chi square tests performed to test the differences among bird species were significant ($P < 0.05$) for five experiments out of ten, specifically experiments 1, 8, 9, 13, and 14 (Table 6). This result shows that the effect of organic farming systems compared to conventional systems on bird abundance is variable and depends on the bird species.

We estimated the log ratio for 36 species for which standard deviation were available. The values of log ratio and the confidence intervals are presented in Fig. 2. For 30 species out of the 36 tested, the log ratio values were higher than zero, showing a positive effect of organic agriculture on species abundance. However, this effect was significant for only ten species. For those species, the abundance was 1.5–18 times higher in organic systems in comparison to conventional systems (Fig. 3).

Fig. 3 Two bird species frequently met in agricultural landscapes which respond positively to organic farming systems. On the *left hand side* skylark (*Alauda arvensis)*, and the *right hand side* Linnet (*Carduelis cannabina*) (Picture from B. Couillens)

A part of the birds' abundance variation among farming systems may be explained by the species' specialization level. Filippi-Codaccioni et al. (2009) found that organic farming was more beneficial for habitat specialist species than for generalist species. However, Wolnicki et al. (2009) found that generalist species benefited more from organic farming and they did not detect a significant difference for specialist species. Our results did not show clear differences in the response of habitat specialist species or generalist species to organic farming. For example, the specialist species skylark (*Alauda arvensis*) was found in significantly higher abundances in organic farming in experiments 2, 13 and 14, but not in experiments 1, 3, 4, 5, 6, 7 (Table 6). Also, the specialist species yellowhammer (*Emberiza citrinella*) was found in significantly higher abundances in organic farming in experiments 1, but not in experiments 4 and 6. Finally, the generalist species wood pigeon (*Columba palumbus*) and chaffinch (*Fringilla coelebs*) were found to have abundances that were positive for organic farming in experiments 1, 3, 4 and 6, but had error bars that overlapped zero (were not significant) in each case.

In our case, most of the ratios were higher than zero indicating a positive effect of organic farming systems compared to conventional systems on bird abundance. However, the 95 % confidence intervals were often large and frequently overlapped the zero thresholds. This shows a high degree of uncertainty about the estimated ratios. As suggested by Bengtsson et al. (2005), the benefit of organic systems may depend on the landscape context. Smith et al. (2010) found that bird species richness was greater in organic systems only in homogeneous landscapes. They concluded organic management produced more food resources for birds, especially invertebrates, compared to conventional farms only in landscapes dominated by intensive agriculture. Belfrage et al. (2005) found greater species richness on small organic farms (less than 52 ha) compared to large organic farms (greater than 135 ha), and concluded that the smaller field size and greater crop diversity of small farms created more heterogeneous landscapes that attracted more birds.

We found 12 articles that provided quantitative data on bird abundance in organic and conventional farms, but only six of these articles provided standard errors and could be included in a formal meta-analysis. The findings from the six articles excluded from our meta-analysis also support our conclusion on the variable effects of organic farming on bird populations. In general, most of the studies found greater abundances of farmland bird species on organic compared to conventional farms. For example, Wilson et al. (1996) found that for a few bird species, organically managed winter cereal fields may provide slightly better wintering habitat than conventionally managed winter cereal fields. In another study, Kragten et al. (2008) found that the nest densities of skylarks were seven times higher on organic farms compared to conventional farms. However in a contrasting study, Bradbury et al. (2000) did not find a difference in breeding success between organic and conventional farms. The three remaining studies found that while organic farming was associated with greater abundances, the results can vary for different species and time periods. Freemark and Kirk (2001) found eight bird species to be more abundant in organic farms and two species more abundant on conventional farms. Wolnicki et al. (2009) found that bird abundances were higher for most, but not all, species on organic farms compared to conventional farms. Chamberlain et al. (2010) found higher bird densities on organic farms for 6 out of 16 species, but no species had higher densities on organic farms during both years of the 2-year study.

3.3 Meta-Analysis of Skylark Crop-Type Preference

For the second part of our meta-analysis, we expected to find an effect of crop type on territory abundance of skylarks. According to AIC (Akaike information criterion) comparisons, the mixed model of a Poisson distribution with crop type included provided the best fit for the data on skylark territory abundance during the breeding season (Table 7). The mean number of skylark territories varied from 0.4 (sugar beet) to 8.7 (set-aside). The box plots of the relationship between skylark territory abundance and crop types show that more skylark territories were found in legumes (including bean, pea and alfalfa crops) and set-aside (fallow land) than other crop types, and these differences were significant (Fig. 4). However, there were no significant differences among all the other crop type.

Set-aside schemes were initially introduced to decrease the overproduction of some crops, but more recently studies have found that set-aside can serve as an important habitat for birds (Van Buskirk and Willi 2004; Bracken and Bolger 2006). Skylarks are one of the farmland bird species that have declined significantly in recent decades, and this species has been found to use set-aside as both foraging and nesting habitat (Browne et al. 2000; Bracken and Bolger 2006). Several reasons can explain why set-aside can be more favorable to skylarks than other crop types. Set-aside and alfalfa both may have smaller mean field sizes than other crop types, and skylarks may prefer to establish territories in small fields (Eraud and Boutin 2002). Wilson et al. (1997) found that while skylarks established territories in legume fields, these crops were too dense for successful nesting. In comparison, these authors also found skylarks to have significantly higher nest survival rates in set-aside compared to cereal fields (Wilson et al. 1997).

Table 7 Effects of crop type on the territory abundance of skylark (*Alauda arvensis*) during the breeding season

Crop type	Crop type coefficient	P-value*
Brassicas	–0.1147	0.7356^{ns}
Grass	0.3677	0.2167^{ns}
Legume	0.8661	0.0023**
Maize	–0.8277	0.0537^{ns}
Miscellaneous crops	–0.0030	0.9927^{ns}
Root vegetable	–0.6203	0.3904^{ns}
Set-aside	1.0130	0.0003**
Spring cereal	–0.1587	0.6393^{ns}
Sugar beet	–0.9307	0.3860^{ns}
Winter cereal	–0.4178	0.2271^{ns}

We used a mixed model with the crop type "bare soil" as the intercept. The Akaike information criterion for the model was 128.6. No significant differences were found among crops except for set-aside and legume, which supported on average two-times more territories than the other crops

*significant at p=0.05; ** significant at p=0.01; *ns* not significant

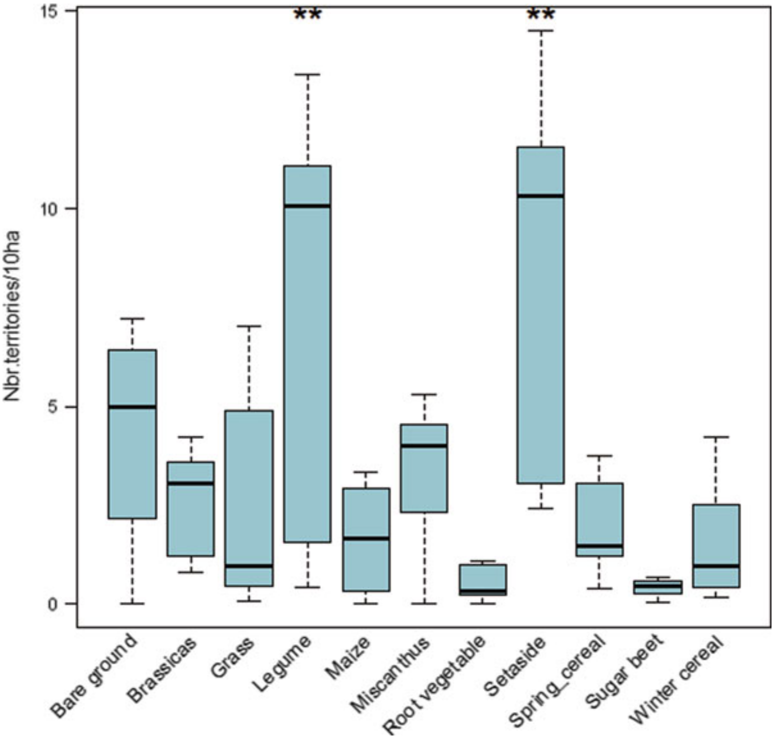

Fig. 4 Box plot showing the effects of crop type on the number of skylark (*Alauda arvensis*) territories during the breeding season. Territory abundances for each crop type are presented below per 10 ha. *Black horizontal bars* represent the median values. Number of Skylark territories mean values of varied from 0.4 (sugar beet) to 8.7 (set-aside). Statistical significance was found for set-aside and legume. These crops support on average two-times more territories than the other crops. ** significant at p=0.01

3.4 Limitations of Current Studies for Meta-Analysis

Our study highlights the need to improve the quality of available data on bird abundances in different farming systems. We found many articles focusing on the relationship between agricultural systems and bird populations; however, we were not able to use the data from most of these publications in a meta-analysis due to several problems. These problems limited the types of analyses we could perform and the data that could be combined for each analysis.

First, few publications provided quantitative information that both linked bird populations to farming practices and could be combined with metrics from other studies. We found many studies that examined the relationship between bird abundance and farming practices using modeling approaches. Most of these studies only published results from the model comparisons, which could not be combined with results from other studies. The authors generally did not provide the field data on bird abundance used to construct the models. We suggest that authors provide these data within publications as supplementary material so they are available for meta-analysis.

The second problem encountered was that publications often did not provide detailed information on the agricultural characteristics of the fields or farms used in the study. Many articles did not provide enough information to classify the farming systems where birds were measured. A better description of farming characteristics, such as frequency of tillage passes or pesticide sprayings, could improve the understanding of the effects of farming practices on observed bird abundances.

Another problem encountered was the large diversity of bird metrics used in the literature. Only a few metrics, such as mean bird abundance per ha, were used in several articles. Many other metrics, such as mean bird abundance per km of transect or mean flock size, were less frequently encountered and could not be converted into a more common metric. In order to use many meta-analysis techniques, the data being compared must have the same metric. Therefore the prevalence of uncommon metrics limited the number of studies we could use for analysis. While response ratios, which have no units, can be used to combine different metrics, not all datasets are suitable for meta-analysis using response ratios (Hedges et al. 1999). Datasets with many zero values in the control group or non-normal distributions of response ratios should not use meta-analysis using response ratios (Hedges et al. 1999). We suggest that authors report common, simple metrics in their studies, such as bird abundance per ha, bird territories per ha or nest abundance per ha.

The final problem was that authors commonly failed to provide measures of variation or replicate numbers for the metrics measured. Part of the appeal of using meta-analysis techniques is the ability to use standard deviations to weigh the contribution of individual measurements. Those measurements with large standard deviations are less influential in calculating the group mean. If standard deviations are not available, we must either omit those data from the analysis or not weigh the data. Both of these options decrease the value of the final analysis. Therefore we advise that the standard deviations (or standard errors) and replicate numbers be given for data in the published literature.

4 Conclusion

We found that organic farming systems supported on average two more birds than conventional systems. This positive effect on bird abundance was found in the majority of the experiments we analyzed. However, this positive effect was significant in less than half of the experiments, showing that the uncertainty about the estimated effects is high. The global trend of organic farming supporting more birds is variable, depending on the bird species and the site considered. We also found that skylarks nesting territories were two-times higher in legume and set-aside fields than in other crops during the breeding season.

We anticipate that the effects of farming practices on bird populations will continue to be an active area of research. We encourage authors to carefully consider how they report their data in their literature so that that their findings can be used in future reviews using meta-analysis. Meta-analysis can be a powerful tool to combine diverse research findings and draw conclusions. However, a meta-analysis is limited by the quantity and quality of data available in the literature. We recommend that authors report their data using simple, common metrics, include standard deviations or standard errors and thoroughly describe the farming systems or practices in question.

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Phytoremediation, Transgenic Plants and Microbes

Kambaska Kumar Behera

Abstract Phytoremediation is a promising technology using plants and microbes to clean up contaminated air, soil, and water. Pollutants pose a global threat for agricultural production, productivity, wildlife and human health. Environmental pollution increasing in many parts of the world. Many methods of preventing, removing and or correcting the negative effects of pollutants exist but their application has either been poorly implemented or not at all. For phytoremediation selected or engineered plants and microbes are used to treat efficiently low to moderate levels of contamination.

Phytoremediation uses the age-long abilities of selected plants and microbes to remove pollutants from the environment. Phytoremediation will probably become a commercially available technology in many parts of the world including India. Currently \$6–8 billion a year is spent on environmental cleanup in the US. In the United Kingdom £4 million are spent on air pollution control and £1.5 million on water-treatment plant, and this cost is expected to increase by 50 % over the next 5 years. The cost of phytoremediation has been estimated as \$25–\$100 per ton of soil, and \$0.60–\$6.00 per 1,000 gallons of polluted water, with remediation of organics being cheaper than remediation of metals. Phytoremediation also offers a permanent *in situ* remediation rather than simply translocating the problem. This review focuses on the major concerns such as phytoremediation technologies, plant and microbes in phytoremediation and, ecological considerations of phytoremediation.

Keywords Contaminant • Heavy metals • Phytoremediation • Phytoextraction • Phytostabilization • Phytovolatilization • Rhizofiltration • Rhizosphere • Soil pollution • Transgenic Plants

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List of Abbreviations

AM	Arbuscular Mycorrhizae
EDTA	Ethylene diamine tetra acetic acid
PCBs	Polychlorinated biphenyls
PCE	Tetrachloroethylene
TCE	Trichloroethylene
TNT	2,4,6-Trinitrotoluene

1 Introduction

Phytoremediation is a novel strategy for the removal of toxic contaminants from the environment by using selected plants and microbes. This concept is increasingly being adopted as it is a cost effective and user-friendly alternative to traditional methods of treatment (Pilon-Smits and Freeman 2006). Toxic metal pollution and xenobiotics in water and soil is a major environmental problem and most conventional remediation approaches do not provide acceptable solutions (Wand et al. 2002). Rapid growth in population and massive industrialisation in recent years has resulted in pollution of the biosphere. Plants and microbes possess some characteristic features which enable them to absorb from soil and water, such heavy metals which are essential for their growth and development (Ghosh and Singh 2005).

Our planet is increasingly polluted with inorganic and organic compounds, primarily as a result of human activities. While inorganic pollutants occur as natural elements in the Earth's crust and atmosphere, anthropogenic activities such as industry, mining, motorized traffic, agriculture, logging, and military actions promote their release and concentration in the environment, leading to toxicity (Nriagu 1979; Wand et al. 2002). Organic pollutants in the environment are mostly manmade and xenobiotic, which are not normally produced or expected to be present in organisms (Pulford and Watson 2008). Many of them are toxic or carcinogenic. Sources of organic pollutants in the environment include accidental releases of fuels and solvents, industrial activities releases chemical and petrochemical, agriculture activities releases pesticides and herbicides and military activities releases explosives and chemical weapons, among others. Moreover, polluted sites often contain a mixture of both organic and inorganic pollutants (Ensley 2000; Reichenauer and Germida 2008). Currently \$6–8 billion a year is spent on environmental cleanup in the US, and \$25–50 billion per year worldwide with ejected 173 million tons of contaminants annually into the atmosphere (Glass 1999; Tsao 2003; http://www.edwardgoldsmith.org/1072/pollution-costs/2/). Most remediation activity still makes use of conventional methods such as excavation and reburial, capping, and soil washing and burning. However, newly emerging biological cleanup methods, such as phytoremediation, are often simpler in design and cheaper to implement (Chaudhry et al. 1998; Khan 2005). Phytoremediation incorporates a range of technologies that use plants to remove, reduce, degrade, or immobilize environmental pollutants from soil and water, thus restoring contaminated sites to a relatively clean, non-toxic environment. The cost of phytoremediation has been estimated as \$25–\$100 per ton of soil, and \$0.60–\$6.00 per 1,000 gallons of polluted water with remediation of organics being cheaper than remediation of metals. In many cases phytoremediation has been found to be less than half the price of alternative methods. Phytoremediation also offers a permanent in situ remediation rather than simply translocating the problem. However phytoremediation is not without its faults, it is a process which is dependent on the depth of the roots and the tolerance of the plant to the contaminant. Exposure of animals to plants which act as hyperaccumulators can also be a concern to environmentalists as herbivorous animals may accumulate contaminate particles in their tissues which could in turn affect a whole foodweb (http://arabidopsis.info/students/dom/mainpage.html). Phytoremediation depends on naturally occurring processes, in which plants detoxify inorganic and organic pollutants, via degradation, sequestration, or transformation. The different uses of plants and their associated microbes for environmental cleanup are discussed (Salt et al. 1998; Meagher 2000; Pilon-Smits 2005; Kramer 2010).

2 Plants and Phytoremediation

Plants are chemical factories that influence their environment not only by uptake of substances but also by exudation of many molecules that are produced in primary and secondary metabolism (Pilon-Smits 2005; Kramer 2010). This lively chemical and physical interaction of plants with their surrounding environment can be used for the remediation of contaminated sites. The contaminants may be taken up and metabolized by plants, immobilized on roots, or degraded by microorganisms living in the areas around the root of the plants. The methods that use plants for the remediation of contaminated sites are categorized under the term “phytoremediation”. The broader term “phytotechnology” is also used; however, this includes other methods such as constructed wetlands or ground cover plants for minimizing erosion (Zeng-Yei et al. 2010).

3 Phytoremediation Technologies

Phytoremediation explores plant’s innate biological mechanisms for human benefit. The subsets of this technology as applicable to remediation process are:

3.1 Phytoextraction

Phytoextraction is the removal of pollutants by the roots of plants, followed by translocation to above ground plant tissues, which are subsequently harvested

(Weyens et al. 2009). Continuous phytoextraction uses plants that accumulate high levels of pollutants over their entire lifetime. Induced phytoextraction enhances pollutant accumulation towards the end of the plant's lifetime, when they attain their maximal biomass, by adding chelators to the soil that reversibly bind the pollutant (usually a metal), releasing it from the soil and making it available for plant uptake. The technique is especially useful when dealing with toxic pollutants that cannot be biodegraded, such as metals, metalloids, and radionuclides (Dowling and Doty 2009). One category of plants that shows potential for phytoextraction, either as a gene source or for direct use, are the so-called hyper accumulators, plants that accumulate toxic elements to levels that are at least 100-fold higher than non-accumulator species (Baker and Brooks 1989; Peer et al. 2005). Hyper accumulator plants tend to grow slowly, which limits their usefulness for phytoremediation. Nevertheless, their growth rate may be improved through selective breeding (Chaney et al. 2007), and the transfer of metal hyper accumulation genes to high-biomass, fast growing species may also help to circumvent the problem (Le Duc et al. 2004, 2006). This technique saves tremendous remediation costs by accumulating low levels of contamination from a widespread area to an easily severable medium. Plants that are promising for phyto-extraction include the mustard plant and some varieties of broccoli and cabbage, which have the required tissue mass to absorb large quantities of metal, tend to pull the metal up into their shoots, and grow relatively quickly (Nakamura et al. 2008; Bi et al. 2011). Nickel and zinc appear to be most easily absorbed, although preliminary results for copper and cadmium are encouraging. The plants involved must have a relatively short lifecycle to facilitate the process which must be economically viable (Kramer et al. 1996).

3.2 Phytotransformation

It is the process by which plants chemically transform contaminants to more stable, less toxic, or less mobile forms. Metals like chromium can be reduced from the carcinogenic, highly mobile hexavalent form to the less toxic, non carcinogenic, less mobile trivalent form that easily binds to organic plant matter and renders the chromium fairly inert (Lee et al. 2006; Newman et al. 1997). The phytotransformation activities of plant mainly done by enzymes or enzyme co-factors (Dec and Bollag 1990). Dec and Bollag (1994) describe plants that can degrade aromatic rings in the absence of micro-organisms. Polychlorinated biphenyls (PCBs) have been metabolized by sterile plant tissues. Phenols have been degraded by plants such as potato (*Solanum tuberosum*),and white radish (*Raphanus sativus*) that contains peroxidase (Dec and Bollag 1994; Roper et al. 1996). Poplar trees (*Populus* spp.) are capable of transforming trichloroethylene in soil and ground water (Newman et al. 1997; Rosselli et al. 2003). Enzymes of particular interest for phytoremediation include: (1) dehalogenase (transformation of chlorinated compounds) (2) peroxidase (transformation of phenolic compounds) (3) nitroreductase (transformation of explosives and other nitrated compounds) (4) nitrilase

Table 1 Important enzymes of plant useful in transforming organic compounds

Sl.No.	Enzyme	Plants known to produce enzymatic activity	Application
1	Dehalogenase	Hybrid poplar (*Populus* spp.), algae (various spp.), parrot feather (*Myriophyllum aquaticum*)	Dehalogenates chlorinated solvents
2	Laccase	Stonewort (*Nitella* spp.), parrot-feather (*Myriophyllum aquaticum*)	Cleaves aromatic ring after TNT is reduced to triaminotoluene
3	Nitrilase	Willow (*Salix* spp.)	Cleaves cyanide groups from aromatic rings
4	Nitroreductase	Hybrid poplar (*Populus* spp.), Stonewort (*Nitella* spp.), parrot feather (*Myriophyllum aquaticum*)	Reduces nitro groups on explosives and other nitroaromatic compounds, and removes nitrogen from rings structures
5	Peroxidase	Horseradish (*Armoracia rusticana* P. Gaertner, Meyer & Scherb)	Degradation of phenols (mainly used in wastewater treatment)
6	Phosphatase	Giant duckweed (*Spirodela polyrhiza*)	Cleaves phosphate groups from large organophosphate pesticides

(transformation of cyanated aromatic compounds) and (5) phosphatise (transformation of organophosphate pesticides) (Frova 2003; Cobbett and Goldsbrough 2002; Fletcher et al. 2005; Subramanian et al. 2006). A list of important enzymes of plant involved in phytoremediation process listed in Table 1.

3.3 Phytostabilization

In this process plant minimize the mobility and migration of potential contaminants in soils. This process takes advantage of plant roots ability to alter soil environment conditions, such as pH and soil moisture content (EPA 1998, 1999; Kramer et al. 2000). Many root exudates cause metals to precipitate, thus reducing bioavailability. This is the most experimental form of phytoremediation, but has potential applicability for many metals, especially lead, chromium, and mercury are stabilized in the soil (Cunningham et al. 1995) and reduce the interaction of these contaminants with associated biota. The success of phyto-remediation is dependent on the potential of the plants to yield high biomass and withstand the metal stress. Besides, the metal bioavailability in rhizosphere soil is considered to be another critical factor that determines the efficiency of metal translocation and phytostabilization process (Ma et al. 2011a).

In recent years, several chemical amendments, such as ethylene diamine tetra acetic acid (EDTA), limestone have been used to enhance phyto-stabilization process (Barrutia et al. 2010; Wu et al. 2011). Even though these amendments increase the efficiency of phytostabilization process, some chemical amendments (e.g., EDTA) are not only phytotoxic (Evangelou et al. 2007) but also toxic to beneficial soil microbes that play important role in plant growth and development (Muhlbachova 2009; Ultra et al. 2005).

3.4 Phytovolatilization

Phytovolatilization is a mechanism by which plants convert a contaminant into a volatile form, thereby removing the contaminant from the soil or water (Singh et al. 1980; Toro et al. 2006; Terry et al. 1992) at the contaminated site. In this process plants, possibly in association with microorganisms, can convert selenium to dimethyl selenide which is the non toxic form (Kumar et al. 1995; Brooks et al. 1998). Dimethyl selenide is a less toxic, volatile form of selenium. Phytovolatilization may be a useful, inexpensive means of removing selenium from sites contaminated with high concentration selenium wastes (Zayed et al. 1998; Zhang and Moore 1997; Pilon-Smits and LeDuc 2009). Similarly, some transgenic plants (e.g., *Arabidopsis thaliana*) have converted organic and inorganic mercury salts to the volatile, elemental form (Watanabe 1997; van Hoewyk et al. 2008; Zeng-Yei et al. 2010).

3.5 Rhizodegradation

Rhizodegradation is a biological treatment of a contaminant by enhanced bacterial and fungal activity in the rhizosphere of certain vascular plants. The rhizosphere is a zone of increased microbial density and activity at the root/surface, and was described originally for legumes by Lorenz Hiltner in 1904 (Curl and Truelove 1986; Khan 2005). Plants and micro-organisms often have symbiotic relationships making the root zone or rhizosphere an area of very active microbial activity (Anderson et al. 1993; Anderson and Coats 1994; Schnoor et al. 1995; Siciliano and Germida 1998a, b; Khan 2005). Plants can moderate the geochemical environment in the rhizosphere, providing ideal conditions for bacteria and fungi to grow and degrade organic contaminants. Plant litter and root exudates provide nutrients such as nitrate and phosphate that reduce or eliminate the need for costly fertilizer additives. Plant roots penetrate the soil, providing zones of aeration and stimulate aerobic biodegradation (Moorehead et al. 1998; Singer et al. 2003; Newman and Reynolds 2004). Many plant molecules released by root die back and exudation resemble common contaminants chemically and can be used as co-substrates. The phenolic substances released by plants have been found to stimulate the growth of Polychlorinated biphenyl (PCB) degrading bacteria (Fletcher and Hedge 1995; Fletcher et al. 1995; Aken 2008; Aken et al. 2010). Recent studies have described enhanced degradation of penta-chlorophenolin the

Table 2 Commonly used plant species in phytoremediation of organic compounds

Name of the Plant	Common Name	Contaminant	Reference
(*Hordeum vulgare* L. cv. Klages)	Barley	Hexachlorobenzene, PCBs, Pentachlorobenzene, Trichlorobenzene	McFarlane et al. (1987)
Panicum antidotale, Panicum maximum, Pennisetum Purpureum, Vetiveria zizynoides etc	Forage grasses	Chlorinated benzoic acids	Siciliano and Germida (1998a)
Myriophyllum aquaticum	Parrot feather	Tetrachloroethane (PCE), Trichloroethane (TCE), TNT	Best et al. (1997)
Populus hybrids	Hybrid poplar	Atrazine, nitrobenzene, TCE, TNT	Burken and Schnoor (1997)
Bromus catharticus	Prairie grass	2-chlorobenzoic acid	Topp et al. (1989)
Glycine max (L.) Merr. cv Fiskby v	Soyabean	Bromacil, nitrobenzene, phenol	Fletcher et al. (1990)
Myriophyllum spicatum	Eurasian watermilfoil	TNT	Hughes et al. (1997)
Helianthus annuus	Sun flower	Cd, Cr, and Ni	Turgut et al. (2004)
Jatropha curcas	Baigaba	Soil contaminated with lubricating oil	Agamuthua et al. (2010)

rhizosphere of wheat grass (*Agropyroncristatum*) (Ferro et al. 1994; Alkorta and Garbisu 2001), increased initial mineralization of surfactants in soil-plant cores (Knabel and Vestal 1992), and enhanced degradation of Trichloroethylene (TCE) in soils collected from the rhizospheres. Anderson et al. (1993) provides a review of microbial degradation in the rhizosphere. Thus, current research suggests the interaction between plants and soil microbes may be an important factor influencing biological remediation of contaminated soils.

Rhizofiltration: Rhizofiltration uses plant roots to filter contaminants directly out of waste streams, in either a hydroponic or a constructed wetland setting. Rhizofiltration is also suitable for inorganics, as the plant material can be replaced periodically. Erosion and leaching often mobilize soil contaminants, resulting in additional aerial or waterborne pollution. This process is used to reduce contamination in natural wetlands and estuary areas although the technology has been extended to engineered applications like gray water and wastewater treatment. It also includes the use of plants to absorb, concentrate, and remove toxic metals from polluted streams. Many submerged and floating aquatic plants are particularly adept for rhizofiltration. Also, flow-through rhizofiltration systems can be designed for removing contaminants from water by pumping the water through a trough planted with contaminant accumulating plants (Knox et al. 1984; EPA 2001). The water moves through the cycle until it is clean enough to be discharged. However, metals and other contaminants become concentrated in plant biomass, which eventually must be disposed (Table 2).

4 Characteristics of Plant Species for Phytoremediation

Populations of metal-tolerant, hyper accumulating plants can be found in naturally occurring metal-rich sites (Baker and Brooks 1989). However, these plants are not ideal for phyto-remediation since they are usually small and have a low biomass production. In contrast, plants with good growth usually show low metal accumulation capability as well as low tolerance to heavy metals.

A plant suitable for phytoremediation should possess the following characteristics: -

1. Ability to accumulate the metal (s) intended to be extracted, preferably in the above ground parts
2. Plants which do not translocate metals to the above-ground parts could be useful for phytostabilization and landscape recreation
3. Tolerance to the metal concentrations accumulated
4. Fastgrowth and effective for metal accumulating biomass and be ideally repulsive to herbivores to avoid the escape of accumulated metal (loid)s to the food chain
5. Have a widely distributed and highly-branched root system
6. Easy to cultivate and have a wide geographic distribution
7. Easily harvestable

5 Transgenic Plants and Phytoremediation

Transgenic plants are genetically modified organisms. In genetic engineering, plants are induced to take up a piece of DNA containing one or a few genes originating from either the same plant species or from any different species, including bacteria or animals (Kassel et al. 2002; Ruiz et al. 2003). The foreign piece of DNA is usually integrated into the nuclear genome, but can also be engineered into the genome of the chloroplast. Foreign DNA may cause an existing enzymatic activity to become up-regulated (over expression) or down-regulated (knockout/knockdown), or may introduce an entirely new enzymatic activity altogether. The expression of the introduced gene can be regulated by using different promoters. The gene product, a protein, may be present at all times, in all tissues (constitutive expression), or only in specific tissues (only in roots) or at specific times (only in the presence of light or a chemical inducer) (Cherian and Margaridaoliveira 2005). Moreover, using different targeting sequences, which function as "address labels", the protein may be directed to different cellular compartments, such as the chloroplast, the vacuole, or the cell wall. In addition to the gene of interest, a marker gene is usually included in the gene construct so that transgenics can be selected for after the transformation event. Usually these marker genes confer herbicide or antibiotic resistance. The introduced genes integrate into the host DNA and are inherited by the offspring like any other gene. In the context of phytoremediation, it is desirable to engineer high-biomass producing, fast-growing plants with an enhanced capacity to tolerate pollutants. In addition, if a pollutant is remediated via accumulation, as is often the case for inorganics, transgenics may be engineered to possess improved pollutant uptake and root shoot translocation abilities. If the pollutant is remediated by degradation, as organics often are, enzymes that facilitate degradation in either the plant tissue or the rhizosphere (the region just outside of the root) may be over expressed. In cases where pollutants are volatilized, enzymes involved in the volatilization process may be over expressed. If a transgenic approach is to be used to breed plants with superior phytoremediation properties, it is necessary to understand the underlying mechanisms involved. Once potential rate-limiting steps have been identified by means of physiological and biochemical experiments, the specific membrane transporters or enzymes responsible can be singled out for over expression. If the genes encoding these proteins are available from any organism, they can be introduced into the plant and the transgenics can be compared with the wild type with respect to pollutant remediation. A great deal of research has been carried out to investigate mechanisms involved in plant uptake of inorganic and organic pollutants and their fate in the plant (Meagher 2000; Burken 2003). Generally, inorganics are taken up by transporters for essential elements, advertently if they are indeed essential, or in advertently if they are chemically similar to essential elements. Once inside the plant they may be detoxified by chelation and by compartmentation in a safe place such as the vacuole. Organics can move passively across plant membranes if they have the right degree of hydrophobicity, corresponding to a log Kow (octanol: water partition coefficient) of 0.5–3.0 (Wu et al. 2006). More hydrophilic organics cannot pass the hydrophobic interior of membranes passively, and there are usually no suitable transporters if they are foreign to the plant. Organic pollutants that do make it into the plant can be detoxified by enzymatic degradation. They may also be stored in the vacuole or cell wall, after enzymatic modification and conjugation to glutathione or glucose, the latter referred to as the “green liver model (Sandermann 1994; Coleman et al. 1997).

6 Microbes and Phytoremediation

A promising alternative to chemical amendments could be the application of microbe-mediated processes, in which the microbial metabolites/processes in the rhizosphere affect plant metal uptake by altering the mobility and bioavailability (Aafi et al. 2012; Glick 2010; Ma et al. 2011a; Miransari 2011; Rajkumar et al. 2010; Wenzel 2009; Yang et al. 2012). When considering approaches to alter heavy metal mobilization, there are several advantages to the use of beneficial microbes rather than chemical amendments because the microbial metabolites are biodegradable, less toxic, and it may be possible to produce them in situ at rhizosphere soils. In addition, plant growth promoting substances such as siderophores, plant growth hormones, 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase produced by plant-associated microbes improve the growth of the plant in metal contaminated soils (Babu and Reddy 2011; Glick 2010; Glick et al. 2007; Kuffner et al. 2008; Lebeau et al. 2008; Luo et al. 2011, 2012; Ma et al. 2011a, b; Miransari 2011; Rajkumar et al. 2010; Wang et al. 2011; Wu et al. 2006). Overall the microbial activities in the root/rhizosphere soils enhance the effectiveness of phytoremediation processes in metal contaminated soil by two complementary ways: (i) Direct promotion of phytoremediation in which plant associated microbes enhance metal translocation (facilitate phytoextraction) or reduce the mobility/availability of metal contaminants in the rhizosphere (phytostabilization) and (ii) Indirect promotion of phytoremediation in which the microbes confer plant metaltolerance and/or enhance the plant biomass production in order to remove/arrest the pollutants.

Plant associated-microbes can also immobilize the heavy metals in the rhizosphere through metal reduction reactions. Chatterjee et al. (2009) reported that the inoculation of Cr-resistant bacteria *Cellulosimicrobium cellulans* to seeds of green chilli grownin Cr (VI) contaminated soils decreased Cr uptake into the shoot by 37 % and root by 56 % compared with uninoculated controls. This study indicates that bacteria reduced the mobile and toxic Cr (VI) to nontoxic and immobile Cr (III) in the soil. According to Abou-Shanab et al. (2007) the lower Cr translocation from root to shoots of water hyacinth is indicative of a Cr reducing potential of rhizosphere microbes. In a similar study Di Gregorio et al. (2005) demonstrated the Se reducing potential of *Stenotrophomonas maltophilia* isolated from the rhizosphere of *Astragalus bisulcatus*. They reported that this bacterium significantly reduced soluble and harmful Se (IV) to insoluble and unavailable Se (0) and thereby reducing the plant Se uptake. These examples illustrate mechanisms, by which metal reducing microbes immobilize metals within the rhizosphere soil and reflect the suitability of these microbes for phytostabilization applications.

Besides, the synergistic interaction of metal oxidizing and reducing microbes on heavy metal mobilization in contaminated soils has also been studied. Beolchini et al. (2009) reported the inoculation of Fe-reducing bacteria and the Fe/S oxidizing bacteria together significantly increased the mobility of Cu, Cd, Hg and Zn by 90 % and they attributed this effect to the coupled and synergistic metabolism of oxidizing and reducing microbes. Though these results open new perspectives for the bioremediation technology for metal mobilization, further investigations are needed to utilize such bacteria in phytoextraction practices.

6.1 Endophytic Bacteria and Phytoremediation

Endophyte-assisted phytoremediation is a promising new field to improve remediation by utilizing microorganisms that live within plants to improve plant growth, increase stress tolerance, and degrade pollutants. These are the bacteria colonizing the internal tissues of plants without causing symptomatic infections or negative effects on their host (Schulz and Boyle 2006). Endophytic bacteria reside in apoplasm or symplasm. Although bacterial endophytes exist in plants variably and transiently (van Overbeek and van Elsas 2008), they are often capable of triggering physiological changes that promote the growth and development of the plant (Conrath et al. 2002).In general, the beneficial effects of endophytes are greater than those of many rhizobacteria (Pillay and Nowak 1997) and these might be aggravated when the plant is growing under either biotic or abiotic stress conditions (Barka et al. 2002; Hardoim et al. 2008). Endophytic bacteria have been isolated from many different plant species (Lodewyckx et al. 2002; Idris et al. 2004; Barzanti et al. 2007; Sheng et al. 2008; Mastretta et al. 2009); in some cases, they may confer to the plant higher tolerance to heavy metal stress and may stimulate host plant growth through several mechanisms including biological control, induction of systemic resistance in plants to pathogens, nitrogen fixation, production of growth regulators, and enhancement of mineral nutrients and water uptake (Ryan et al. 2009). Additionally observed beneficial effects due to bacterial endophytes inoculation are plant physiological changes including accumulation of osmolytes and osmotic adjustment, stomatal regulation, reduced membrane potentials, as well as changes in phospholipid content in the cell membranes (Compant et al. 2005). Further, the endophytic bacteria isolated from metal hyper accumulating plants exhibit tolerance to high metal concentrations (Idris et al. 2004). This may be due to the presence of high concentration of heavy metals in hyper accumulators, modulating endophytes to resist/adapt to such environmental conditions. It is also possible that the metal hyper accumulating plants may simultaneously be colonized by different metal-resistant endophytic bacteria ranging wide variety of gram-positive and gram-negative bacteria (Rajkumar et al. 2009).

6.2 Arbuscular Mycorrhizae and Phytoremediation

AM fungi are ubiquitous soil microbes occurring in almost all habitats and climates, including metal contaminated soils (Chaudhry and Khan 2002; Mastretta et al. 2006) and are considered essential for the survival and growth of plants growing in nutrient especially phosphorus deficient derelict soils. However, polluted wastelands contain reduced population diversity and numbers of autochthonous AM strains which are heavy metal tolerant (Chaudhry and Khan 2003). Studies with AM fungi have focused on their ability to enhance nutrient uptake in a nutrient deficient soil and have ignored the role they may play in phytoremediation. The prospect of fungal symbionts existing in metal contaminated soils has important implications for phytoremediation (mycorrhizo-remediation) of metal contaminated soils as AM fungi help plant growth through enhanced nutrient uptake. Plant species belonging to plant families *Chenopodiaceae, Cruciferaceae, Plumbaginaceae, Juncaceae, Juncaginaceae, Amaranthaceae* and few members of *Fabaceae*, are believed not to form a symbiosis with AM (Smith and Read 1997). In some cases, arbuscular mycorrhizal fungi have been shown to increase uptake of metals (Liao et al. 2003; Whitfield et al. 2004; Citterio et al. 2005) and arsenic (Liu et al. 2005; Leung et al. 2006) in plants but other studies showed no effect (Trotta et al. 2006;

Wu et al. 2007) or decreased concentrations in plant tissues. The contrasting results are difficult to evaluate and may be partly due to different experimental settings (Liu et al. 2005; Leung et al. 2006) versus field studies (Trotta et al. 2006; Wu et al. 2007) as in the case of arsenic uptake in *Pteris vittata* inoculated with arbuscular mycorhizal fungi.

6.3 Importance of Endophytic Bacteria

(i) Genetic engineering of endophytic bacteria is easier than the genetic engineering of plants. In addition, if strains are selected that can successfully colonize multiple plants, only one bacterial line would need to be created.

(ii) Gene expression within endophytes might be useful as a site-monitoring tool. Using plants as soil and groundwater samplers would yield both active and passive sampling characteristics at a low cost. Specific gene expression within endophytes, such as that possible with quantitative polymerase chain reaction, might then be an effective measurement tool. This approach would lessen the need for expensive sampling and analysis on heterogeneous sites.

(iii) Bacterial endophytes might function more effectively than bacteria added to soil would because of a process known as bioaugmentation. The plant provides aready-made environment for endophytic bacteria so competition pressure against colonization of the desired organism, as often occurs in soils, would be reduced.

(iv) If bacterial lines are carefully selected so that the strains are at a competitive disadvantage when not living as a plant endophyte, the movement of engineered genes in the environment would be greatly reduced.

7 Advantage and Disadvantage of Phytoremediation

Advantages	Disadvantages
It works on a variety of organic and inorganic compounds	It may take several years to remediate
It can be either in *situ/ex situ*	It may depends on climatic conditions
The technique is easy to implement and maintain	The technique restricted to sites with shallow contamination within rooting zone
Less costly compared to other treatment methods	Harvested biomass from phytoextraction may contain hazardous waste
Ecofriendly and aesthetically pleasing to the public	Consumption of contaminated plant tissue is also a concern
Reduces the amount wastes to be landfilled	Possible effect on the food chain

8 Ecological Considerations

Many ecological issues need to be evaluated when developing a remediation strategy for a polluted site. In particular, one has to consider how the phytoremediation efforts might affect local ecological relationships. As described above and shown in Fig. 1, phytoremediation-related processes can change the location or chemical makeup of contaminants in the polluted area. The question is, how do those processes affect the ecological interactions among the biota in the ecosystem? The choice of plant species for remediation will, of course, greatly influence which ecological partners and interactions will be present at the site, and consequently the fate of the pollutant. The direct ecological partners of phytoremediator plants include bacteria, fungi, animals, and other plants, all occurring inside, on, or in the vicinity of the roots and shoots of the phytoremediator plants (Fig. 1). These partners may be affected positively or negatively by the ongoing phytoremediation process. If the plants stabilize or degrade the pollutant, there by limiting its bioavailability and concentration, the phytoremediation process will probably benefit other organisms in the area. If, on the other hand, the plants accumulate the pollutant or its degradation products in their tissues, this may adversely affect microorganisms that live on or inside the plant (Angle and Heckman 1986), as well as root and shoot herbivores, and pollinators. Volatilization of a pollutant will simultaneously dilute and disperse the pollutant, which may affect ecosystems both on and off the site (Li et al. 2003; Lai et al. 2008). In addition to the direct ecological partners of the phytoremediator plants, the phytoremediation processes may also affect other trophic levels. If a

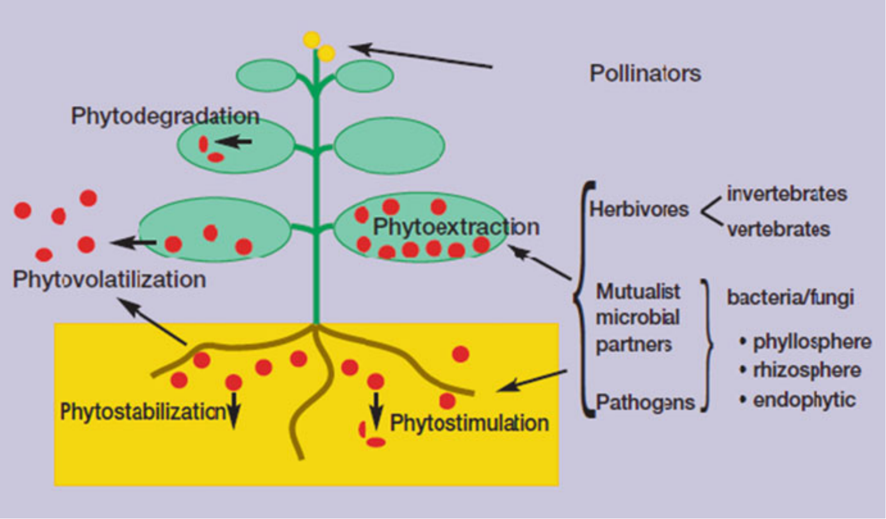

Fig. 1 Schematic overview of phytoremediation methods. Shown on the *right* are some ecological partners of the plants that may influence phytoremediation

pollutant is accumulated by the plant, this may facilitate its entry into the food chain, as depicted in Fig. 1. Conversely, these ecological partners may affect the remediation process positively or negatively, by interacting with the pollutant directly or with the plants. Herbivores or pathogens may hamper plant growth and thus the phytoremediation efficiency. On the other hand, rhizosphere or endophytic microorganisms may make pollutants more bio available for plant uptake, or may assist in the biodegradation process. While it is known that plant–microbe consortia often work together in remediation of organic pollutants (Olson et al. 2003; Barac et al. 2004; Van Aken et al. 2004; Taghavi et al. 2005), much still remains to be discovered about the nature of the interactions and the molecular mechanisms involved (e.g., signal molecules, genes induced).

Chaney et al. (1997) calculated that metal tolerance and hyper accumulation would be more important to phytoremediation than high biomass production. For an effective development of phytoremediation, each element must be considered separately because of its unique soil and plant chemistry. On the other hand, metals rarely occur alone and adaptive tolerance may be needed for several metals simultaneously, even though phytoextraction of only one metal would be the goal. In some cases it might be desirable also to extract more than one metal at the same time. To merge the high metalloid accumulation capacity with such preferable plant anatomy and growth characteristics, efforts are being made for the genetic manipulation of candidate plants in order to improve their uptake, translocation and tolerance.

9 Conclusion

A polluted site and pollutant poses a risk to the environment as well as to the biota. This risk is correlated with the toxicity and concentration of the pollutant, the likeliness of its mobilization and spread by water and wind, and the proximity of sensitive and interaction to the ecosystems. The remediation strategies available for site specific cleanup will vary in their effectiveness in alleviating the existing risks and in the characteristics of their associated risks, and will also have different timelines and price tags. For each individual site, these initial risks will need to be addressed and evaluated in order to design an optimal remediation approach. Once the remediation strategy is decided, steps must be taken to lessen the associated risks. In the case of phytoremediation, careful choice of plant species and management practices are key to promoting ecological restoration and preventing pollutant dispersal. Where possible, native plant species with effective remediation properties and that provide natural hydraulic control (e.g., trees) and soil stabilization (e.g., grasses) should be selected. Drip irrigation can be used to prevent leaching, and fencing will minimize pollutant entry into the food chain. Phytoremediation is an interdisciplinary technology that will benefit from research in many different areas. Much still remains to be discovered about the biological processes that underlie a plant's ability to detoxify and accumulate pollutants. Better knowledge of the biochemical mechanisms involved may lead to: (1) the identification of novel genes and the subsequent development of transgenic plants with superior remediation capacities; (2) a better understanding of the ecological interactions involved (e.g., plant microbe interactions); (3) the effect of the remediation process on the existing ecological interactions; and (4) the entry and movement of the pollutant in the ecosystem. In addition to being desirable from a fundamental biological perspective, this knowledge will help improve risk assessment during the design of remediation plans (including the additional risks of transgenic plants) as well as alleviation of the associated risks during remediation.

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Management of Pathogens of Stored Cereal Grains

Neeta Sharma and Avantina S. Bhandari

Abstract Biodeterioration of grains due to pests such as insect infestation and molds is a chronic problem in tropical and subtropical countries. This problem is aggravated due to the hot and humid climate. Consumption of infected grains induces hazardous health effects causing hepatic carcinoma and other serious disorders. Because of the high consumption of grains protection and management is mandatory. Traditionally, safe storage of harvested produce is done by carefully selecting the storage site, using proper storage structures, cleaning and fumigation. Safe storage also involves proper aeration of grains, physical separation of infected grains, drying, irradiation and heat treatment. Synthetic pesticides have been used for protection of stored food grain due to good availability. The application of fungicides to grains after harvest to reduce decay has been increasingly impeded due to: the development of resistance to many key pesticides; the lack of alternative pesticides; toxicity and negative public reception.

Therefore alternatives to synthetic pesticides are needed. The distinct propensity towards a 'Trek back to nature' has become evident in recent past, especially in the field of pesticides. Recent reports show the development of natural products such as botanicals. Botanicals are secondary plant metabolites that can be commercialized as non-phytotoxic, systemic, easily biodegradable pesticide. Antagonistic microorganisms as an alternative approach to fungicides and as biocontrol agents have also been used effectively. Molecular biology has also been instrumental in providing some techniques for post harvest and storage management which is a boon for agricultural advancement.

Keywords Grains • Biodeterioration • Biodeteriogens • Synthetic chemicals • Natural products • Bio-agents

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1 Introduction

Grains/seeds are the mini reservoirs of energy packed with nutritive values. For a number of developing countries, cereals and grain legumes represent the basic element of the population's diet, especially for the lowest-income, generally rural, groups. Food security is both qualitative and quantitative terms, i.e. maintaining healthy and bulk food with continuous supply. Aggregation of these products are essential as buffer stock throughout the year as an insurance against crop failure in times of drought, excessive rainfall or any other natural calamities, on one hand while on the other side their importance as seed cannot be denied as they are essential for any seed programme to sow the crop in the next season, to maintain parental lines for the production of hybrid seed, to conserve germ-plasm for breeding purposes and for seed trade at national or international levels.

The era of "Green revolution" was dominated by "the Gray". Application of fertilizers and pesticides to crops became a norm and cereals were no exception. Though direct chemical treatment of stored grains is restricted to grain for seed purpose only and not for food and feed, but indirect use as fumigants such as phosphine, hydrogen cyanide, methyl bromide, ethyl formate, sulfur dioxide, chloropicrin and many more continue till date due to increased market pressure, international trade and higher standards sought by the consumers (Marin et al. 2000; Navarro 2006).

The continuous supply of food do not end with the harvest of satisfactory yields of plant products but harvesting marks the termination of one phase of plant protection and the beginning of another, the second phase of plant protection is also very important.

The damage and deterioration of food commodities is the result of triple agencies viz. fungi, insects and rodents under different conditions of storage. The most sustainable and feasible method of food security can be management of postharvest losses occurring due to nonavailability of proper storage and transportation facilities and improper handling methods, resulting in greater levels of injuries or wounds during harvesting and transit. The incidence of pest and diseases on crops has also negatively affected the agro-allied industries. Additionally, pathogens are significant destroyers of food stuffs and grains during storage rendering them unfit for human consumption by retarding their nutritative value and often by producing mycotoxins. About one-third of the world agriculture produce is destroyed by a combination of both pest and diseases.

The most conventional and common method of pest and disease control is through the use of synthetic chemicals. These chemicals are generally persistent in nature. Upon entering the food chain they destroy the microbial diversity and cause ecological imbalance.

Furthermore, the use of synthetic chemicals has also been restricted because of their carcinogenicity, teratogenicity, high residual toxicity, ability to create hormonal imbalance, spermatotoxicity, long degradation period, environmental pollution and their adverse effect on food and side effects on humans (Feng and Zheng 2007).

The aim is not only to prevent postharvest losses but also to go “green” and “healthy” in order to recover and reap the benefits of the “stolen harvest”. Globally, greater restrictions on pesticide’s use in the developed nations have resulted in increasing trends for natural, non-chemical, physical, biotechnological and/ or organic approaches to disease control.

2 The Losses in Stored Grains

Grain produced is not a grain until it is consumed without quality loss. Despite, employing best methods of food preservation to save the products, nearly 30 % of the harvest is lost due to poor and improper handling and faulty storage practices. According to the World Bank “Missing Food” report of 2011, loss is estimated to be 7–10 % at the farm to market level and another 4–5 % at market and distribution level. This loss constitutes 12–16 million tons of grain for which average annual per capita consumption is approximately 15 kg. This level of loss, caused primarily by improper harvesting and processing methods, improper storage, and loss during transportation, constitutes enough grain to feed approximately 70–100 million people.

Agricultural commodities produced on the farm fields have to undergo a series of operations such as harvesting, threshing, winnowing, bagging, transportation, storage, processing and exchange before they reach the consumer, and there are appreciable losses in crop output at all these stages. Estimates of the postharvest losses of food grains in the developing nations are put at 25 %. Figure 1 presents the part of the initial production lost or wasted, at different food supply chain stages, for cereals in different regions of the world. The causes of the postharvest losses in grains are manifold and can occur at any stage between harvest and consumption.

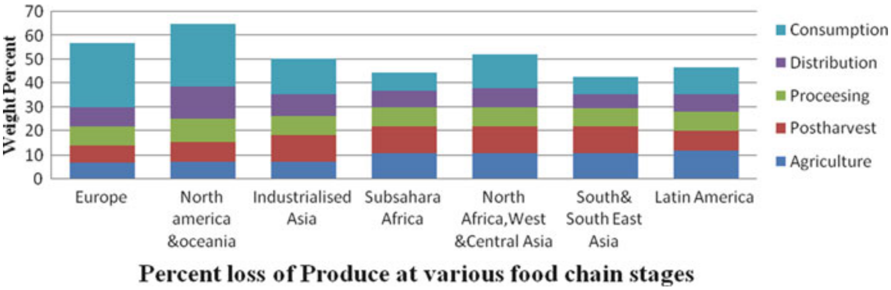

Fig. 1 Losses in cereals at different food supply chain stages, in different regions (FAO 2011)

3 Agents and Factors Responsible for Biodeterioration of Stored Grains

During storage, quantitative as well as qualitative losses occur due to insects, rodents and micro-organisms. Fungus in stored grain is the most difficult to eradicate, fungal deterioration of grain is a dynamic process and interrelationships between biotic and abiotic factors are so complex that is considered as a manmade ecosystem (Wallace and Sinha 1981). The principal abiotic factors which control fungal growth and mycotoxin elaboration are moisture, temperature, atmosphere, aeration, pH and condition of the grain. All of these factors interact as deterioration progresses, but moisture and temperature are the key factors affecting the process. Sometimes mechanical injury is responsible for the entry of pathogens in insufficiently dried grain.

3.1 Abiotic Factors

3.1.1 Temperature

Temperature is very important factor which is responsible for post harvest losses. Temperature within a store is affected by the sun, the cooling effect of radiation from the store, outside air temperature, heat generated by the respiration of both the food in store and any insect pest present. Differences in temperature between different portions of a grain bulk result in rapid transfer of moisture from warmer to cooler regions promoting insects and fungal activities (Sharma 2007). A 10 °C rise in temperature causes an approximately two-fold increase in the rate of reaction. Thus, cold storage will retard such changes, as fat oxidation and vitamin loss. Many dried food grains benefit from even a small reduction in their storage temperature, and cool and dry conditions can greatly reduce the rate of development of brown discoloration and off-flavors from entering the store.

3.1.2 Relative humidity

All micro-organisms, including moulds, require moisture to survive and multiply. If the moisture content in a product that is to be stored is low, micro-organisms will be unable to grow, provided that the moisture inside the storage structure is also kept low. Moisture should therefore, be prevented. Generally, provided grain is stored at a moisture content equivalent to ≤ 0.70 water activity then no spoilage will occur. However, since grain is often traded on a wet weight basis, inefficient drying system can lead fungal activity and concomitant mycotoxin production which renders grain useless for food or feed.

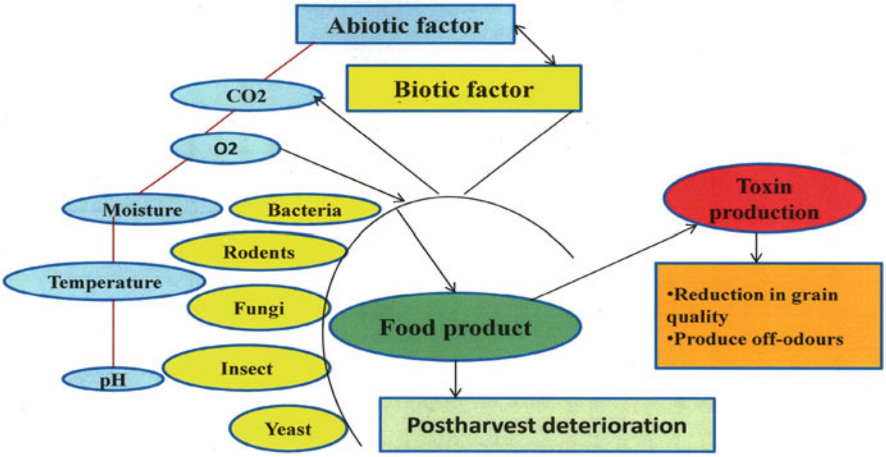

Fig. 2 Different abiotic and biotic factors responsible for postharvest deterioration

3.1.3 pH and Oxygen

Field fungi do not grow in storage environment due to low pH and low oxygen, which is not conducive for their survival as storage fungi. The major field fungi are species of *Alternaria, Helminthosporium, Fusarium, Epicoccum* and *Nigrospora.* Storage fungi are predominantly species of *Aspergillus*, *Penicillium* and *Fusarium*.

3.2 Biotic Factors

Microorganisms are ubiquitous in terrestrial ecosystems from which they are disseminated to contaminate plant communities. The ripening seed is no exception and is contaminated by a wide range of insects, bacteria, yeasts and filamentous fungi via air, insects, rain splash, equipment and agronomic practices. Fungus in stored grain is the most difficult enemy to recognized, for it cannot be easily seen as the two other major pests; insects and rats. Pre-harvest insect infection can lead to increased infection of mycotoxin producing fungi. The role of insect pest should not be neglected as they may be integrally involved in the dominance of mycotoxigenic species by helping in dispersal and acting as vectors and carriers of the toxins through grains. Therefore, aggregation of abiotic factors and biotic factors are responsible for poor post harvest management that can lead to rapid deterioration of food grain quality, severely decreasing germinability and nutritional value of stored grain, which is also depicted in Fig. 2.

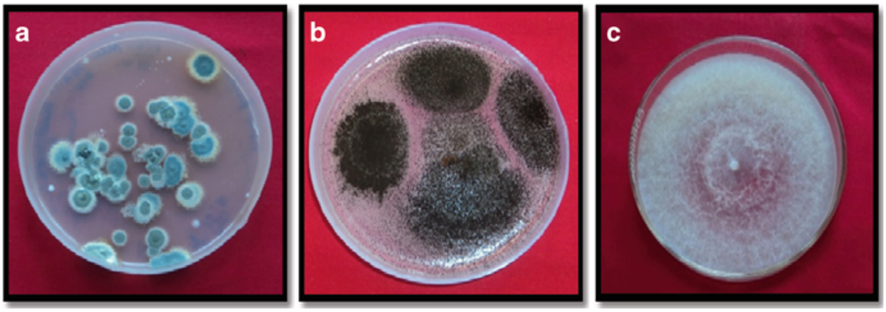

Fig. 3 Mycotoxin producing fungal genera isolated from grains. (**a**) *Penicillium* spp., (**b**) *Aspergillus* spp., (**c**) *Fusarium* spp.

3.3 Fungal Biodeterioration of Stored Grains

Fungal biodeterioration is defined as any change resulting from the activities of fungi which renders a product unsuitable for its intended use or reduces the economic value of the materials. The fungal growth may cause many deleterious effects on food grains. A dull appearance and musty smell of grain invariably means mould growth, contamination of cereal commodities by moulds and mycotoxins results in significant hazard to the food chain.

Fungi impart various colors to the invaded commodity changing its original appearance, and rendering it unfit for use in value addition and production. Fungal activity reduces viability of the seeds by destroying the embryo; they also introduce biochemical changes in the infected seeds. Because most moulds have high lipolytic activity, fats and oils in grain are readily broken down into free fatty acids and partial glycerides during the fungal deterioration of grains.

The storage fungi produce number of mycotoxins in food grains and other products. Mycotoxins are a group of highly toxic secondary metabolites of the fungi produced under certain favorable environmental conditions (Hope et al. 2005) depending on the definition used some 300–400 compounds are now recognized as mycotoxins, but only a few present significant food safety challenges. According to FAO estimates 25 % of the world foods are affected by mycotoxin each year.

Mycotoxins can mean ‘life or death’ for cereal grain as a marketable and consumable commodity. Mycotoxins are well known to be potentially mutagenic, carcinogenic teratogenic, hepatotoxic and immunosuppressive and also inhibit several metabolic system (Sinha and Choudhary 2008). Predominant species that lead to mycotoxin contamination in cereals are *Aspergillus, Penicillium* and *Fusarium.* Figure 3 shows the fungi isolated from different stored grains. It has been estimated that around 25 % of cereals (world production about 2,200 million tonnes in 2009) can be infected by fungi and hence by mycotoxins.

Table 1 summarizes the main cereal moulds and the mycotoxins they produce.

Table 1 Cereal moulds and their toxins

Cereal moulds	Mycotoxins
Fusarium graminearium, F. culmorum	Deoxynivalenol (DON vomitoxin), nivalenol, zearalenone
Fusarium poae, F. langsethiae	T2 toxin and HT2 toxin
Fusarium verticillioides, F. proliferatum	Fumonisins
Aspergillus flavus, A. parasiticus	Aflatoxin B1,B2 G1 and G2
Aspergillus ochraceus, A. verrucosum	Ochratoxin A
Aspergillus chevalieri, Penicillium notatum	Xanthocillin
Aspergillus nidulans, A.versicolor	Sterigmotocystin
Aspergillus ruber, Penicillium rubrum	Rubratoxin
Aspergillus niger	Oxalic acid
Penicillium islandicum	Islanditoxin
Penicillium citrinum, P. viridicatum	Citrinin
Penicillium patulinium, P. expansum	Patulin

4 Management of Postharvest Losses in Cereals

If left uncontrolled, these fungi will cause deterioration of food products and many other articles of commerce and industry. These should be treated very carefully and at the first step it done by implementation of good agricultural practices to prevent infection already in the field.

These strategies cover practices such as insect control, irrigation during drought conditions, planting and harvesting dates and cropping patterns and use of resistant varieties (Choudhary and Kumari 2010). For effective post harvest management of stored commodities clear monitoring criteria and effective implementation in relation to abiotic and biotic factors and hygiene is required in order to ensure that biodeterioration is minimized and that stored grain can proceed through the food chain for processing (Magan and Aldred 2007).

Public opinion demands a reduction in the use of synthetic chemicals due to the direct exposure to the treated commodities and various other side effects on human's, environment as well as animals. Further the effectiveness of the post harvest chemical treatment decreases with the appearance of resistant strains. The intense selection pressure of pesticide residues on the treated perishable commodities is responsible for the rapid spread of resistance among pathogens.

In the urge for safe and ecofriendly alternatives a variety of methods have come to light in the recent past, which can be categorized as:

- Physical methods
- Biological methods
- Non-chemical methods (botanicals, antimicrobial proteins, essential oils)
- Biotechnological tools (genetically modified crops)

4.1 Physical Methods

These methods include physical separation, drying, irradiation, heat treatment etc. One of the most significant management tools can be a proper design of storage structure and methods.

4.1.1 Physical Separation

During harvesting and other farm level activities, grain is damaged and large amount of foreign material is added to it, which may lead to easy susceptibility to contaminations in storage. Physical separation of damaged and infected grains is achieved either by manual separation or by electronic sorter. Another approach to separate infected seeds from healthy ones is through floating and density segregation mechanism, where infected seeds float on water. This mechanism can be considered as an effective first line defense for produce.

4.1.2 Drying

Drying of the produce as quickly and evenly as possible after harvesting up to the critical moisture level keeps the grain safe from insects and moulds for longer duration. The most prevalent method of drying is sun drying. Other methods may include mechanical drying. Drying can also be achieved by using infrared, microwave and sonication techniques.

4.1.3 Irradiation

The use of ionizing radiation to control the microbial growth in foods or medicine has been investigated since the last nineteenth century. Exposing food grains to radiation treatment delays spoilage and improves safety by eliminating or reducing pathogenic microbes. Scientific research has proved that consumption of irradiated food is absolutely harmless.

Use of gamma radiation is widely accepted as they can penetrate foods to a depth of several feet. The advantage of gamma radiation is the high penetrability and uniformity of the dose.

The susceptibility of fungi and/or their spores to gamma radiation is well established and has proved to be an efficient method in preventing food and feed contamination with mycotoxin producing fungi.

Abouzeid et al. (2003) found that gamma irradiation generally decreased the counts of *Fusarium verticilliodes* in both buffered saline solution and in corn, and this reduction was proportional to gamma irradiation dose applied.

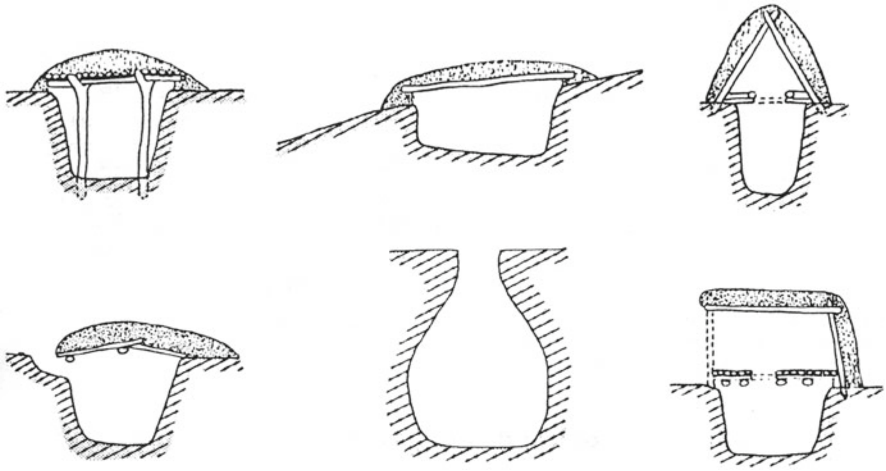

Fig. 4 Range of storage structures

Aziz et al. (2007) found that the viable counts of *Fusarium* in seeds decreased by increasing the radiation dose applied.

Braghini et al. (2009) evaluated the effects of a range of gamma radiation doses on the growth of *Alternaria alternata* in artificially inoculated cereal samples of corn.

4.1.4 Storage Structures and Methods

For safe and scientific storage it is important to carefully select the storage site, storage structure, undertake cleaning and fumigation and ensure proper aeration of grains. Nearly 70 % of the total production of food grains in India are retained at home level in indigenous storage structures, where inadequate storage conditions enhance the chances of fungal attack and contamination of food and feed. Grains can be stored indoors, outdoors or at underground level. The storage structures range from mud structure to modern bins (Fig. 4).

If storage ecosystem can be sealed to prevent air from entering or leaving it, the respiratory metabolism of insects, moulds and the grains itself will lower the oxygen content and raise the carbon dioxide content of the inter granular atmosphere to a level where aerobic respiration is no longer possible.

This is the principle behind hermetic storage; this has resulted in safe, pesticide free and sustainable storage. The present day hermetic sealed storage makes use of poly vinyl chloride (PVC) liners that conforms to pre-requisite specifications of durability to climate, gas-permeabilities, and physical properties (Ferizli et al. 2001; Bortosik et al. 2008).

Fig. 5 Dual culture of *Fusarium* spp. and *Trichoderma* spp. showing inhibition of test fungus

4.2 Biological Control

A number of biological control agents have been reported to inhibit growth of mycotoxigenic fungi and subsequent mycotoxin biosynthesis. A number of environmental and agronomic factors influence grains infection by fungi at preharvest stage. One approach is to incorporate the use of biocontrol agents in appropriate agricultural practices to control mycotoxigenic fungi in the field. A toxigenic strain of *Aspergillus flavus* or *A. parasiticus* reduced aflatoxin contamination of agricultural products, such as peanuts (Dorner et al. 2003) rice, maize. The effect is believed to be mediated mainly through competition for substrate and through the potential production of inhibitory metabolites (Dorner and Lamb 2006).

A biological control system using an endophytic bacterium, *Bacillus subtilis* has been developed that shows great promise for reducing mycotoxin accumulation during the endophytic growth phase of *Fusarium verticillioides* (Tsitsigiannis et al. 2012). It was shown that this isolate occupied the same ecological niche as *Fusarium verticillioides* within the plant, and it was postulated to act competitively to the pathogen.

An isolate of *Trichoderma* gave promising results in postharvest control of the development and toxin accumulation of *Fusarium verticillioides* on maize in storage conditions (Bacon et al. 2001).

The efficacy of *Trichoderma* has been tested against the storage pathogens of cereals. The picture below shows a dual culture of *Trichoderma* with *Fusarium* sp., the mycelial growth of test pathogen is arrested at an early phase as compared to control. The activity of *Trichoderma* spp. as biocontrol can be attributed to hyperparasitism or antibiosis (Fig. 5).

There are numerous reports regarding the antifungal properties of various lactic acid bacteria, which can exhibit activities against several *Aspergillus* species and a broad range of other mycotoxigenic fungi.

Antifungal activity of *Lactobacillus sanfrancisco* CBI inhibited spoilage moulds from genera *Monilia*, *Aspergillus*, *Penicillium* and *Fusarium*. These bacteria produce antimicrobial compounds such as lactic acid, acetic acid, hydrogen peroxide, bacteriocins and low molecular weight proteins during carbon source metabolism.

Table 2 Various bioagents which control mycotoxigenic fungi

Targeted mycotoxigenic fungus	Commodity	Biocontrol agents
Aspergillus flavus *A. parasiticus*	Peanuts, rice maize and corn and cotton seed	Atoxigenic *A. flavus* strains AF36 and NRRL,21882
		Lactobacillus casei
		L. sanfrancisco CBI
		Streptococcus
		Bifidobacterium
		Trichoderma spp.
		Phoma spp.
		Rhizopus spp.
		Sporotrichum spp. *ADA.*
		Sporotrichum spp. *SF*
		Alternaria spp.
Fusarium verticillioides *F. graminearum* *F. culmorum*	Barley, maize and wheat	Endophyte *Bacillus subtilis*
		Bacillus amloliquefaciens BA-S13,
		Bacillus spp. NRRL 302
		Bacillus subtilis H-08-02
		Bacillus cereus L-07-01
		Bacillus mycoides S-07-01
		Microbacterium oleovorans DMS 1 16091
		Enterobacter hormomaechei EM-5621
		Lysobacter enzymogenes strain C3
		Pseudomonas fluorescens strains MKB 158 and MKB 249
		P. frederiksbergensis strain 202
		Fusarium equiseti (G9)
		Cryptococcus spp.
		Khuyveromyces spp. L14 and L16

They compete with other species by acidifying the environment and rapidly depleting nutrients (De Muynck et al. 2004; Kabak and Dobson 2009). Table 2 shows various fungal, bacterial and yeast bioagents that control mycotoxigenic fungi.

4.3 Non-Chemical Methods

4.3.1 Plant Extracts

Plants are believed to be boon to human kind as they provide us with food, fodder, housing material etc. and they may be used for all possible things in the purview of human imagination.

In present times the use of plants has gained importance in plant protection also, and the use of plant extract is widely acknowledged in this field.

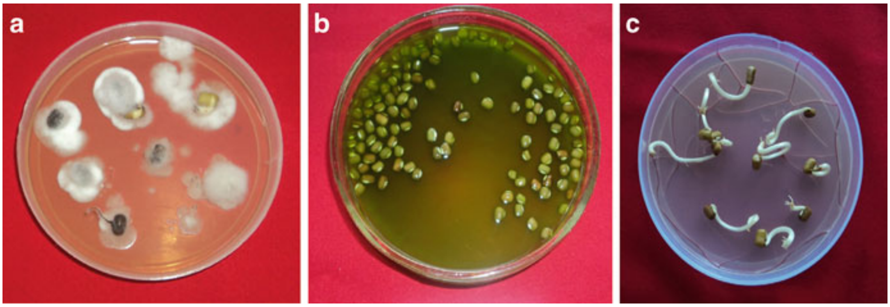

Fig. 6 Effect of *Adenocalymma alliaceum* extract. (**a**) Before treatment, (**b**) Seed treatment, (**c**) After treatment

The first step towards the isolation of the active component is screening of plant extracts for their antimicrobial activity. Water and/or different organic solvents, singly or in combination, are generally used in the preparation of extracts.

Antifungal activity assays of leaf extract obtained from various plants are tested. Singh and Singh (2000) screened 50 plants belonging to 27 families for their antifungal activity against *A. flavus* and A. *niger and* found *Trachyspermum ammi, Allium sativum Syzygium aromaticum* and *Plectranthus rugosus,* effective against both the species of *Aspergillus*.

Plant extracts of *Zingiber officinale*, bulbs of *Allium sativum* and *A. cepa,* leaves of *Adathoda vasica, Lippia alba, Azadirachta indica,* stem of *Cuscuta reflexa,* root of *Vinca rosea* and seeds of *Nigella sativa* were tested for their efficiency in vitro against *Aspergillus* and *Penicillium* spp. in wheat (Kumar et al. 2007). Aqueous extracts of *Termanalia australis* has been reported to be effective in inhibiting *Aspergillus* strains by Carpano et al. (2003). All the plant extracts reduced the incidence of seed borne fungi significantly and increased seed germination, the number of healthy seedlings and the vigor index. Neem and garlic extracts controlled the intensity of the fungi completely (Hasan et al. 2005).

Aqueous extract of *Adenocalymma alliaceum* is also reported to possess a wide spectrum of fungitoxicity against fungi associated with deterioration of cereals and legumes. In addition, it possesses antiaflatoxigenic activity and is non-phytotoxic. (Shukla et al. 2008). *Garcinia, Xanthium, Ammi,* and *Polymnia sonchifolia* have also been exploited to control growth of moulds and aflatoxin (Joseph et al. 2005).

Adenocalymma alliaceum was tested to cure mycotoxigenic *Fusarium* spp., infecting legumes, and showed best cure after 3 h dipping in 100 % concentration (Fig. 6).

Germination of legume seeds was unaffected by the extract application but rather seedling growth was enhanced.

Organic solvents used for extract preparation also showed efficacy as antifungal. Extracts of aerial parts of *Achillea clavennae, Achillea holosericea, Achillea lingulata, Achillea millefolium* (hexane: ether: methanol = 1:1:1) were tested for antifungal activity by disc diffusion assay against *A. niger*. All four species exhibited antifungal activity against tested strains (Stojanvoic et al. 2005).

Parekh and Chanda (2007) evaluated the antifungal activity of *Trapa natans* L. fruit rind, extracted in different solvents of increasing polarity and observed that

1,4- dioxin, chloroform, acetone, dimethylformamide, ethanol and water did not reveal any activity against *A. niger*.

The activity of the extracts can be attributed to the presence of phytochemicals which are produced by mevalonic acid pathway as secondary metabolites. Useful antimicrobials phytochemicals are phenolics and poly phenols, quinones, flavones, flavanoids and flavanols, tannins, coumarins, terpenoids and essential oils, alkaloids, lectins and polypeptides.

Secondary metabolites represent a large reservoir of chemical structures with biological activity. Investigations on the antifungal active methanol fraction of the root of *Epinetrum vellosum* (Exell) troupin (Menispermaceae) led to the isolation of the bisbenzylisoqunilone alkaloid cocsoline, which displayed significant antifungal activity with a minimum inhibitory concentration (MIC) for *A. flavus* and *A. niger* of 31.25 g/ml (Otshudi et al. 2005).

Two known sequiterpene lactones, vernolide and vernodalol, obtained by phytochemical analysis of the leaves of *Vernonia amygdalina* exhibited significant antifungal activity. Vernolides exhibited high activity and the 50 % lethal concentration (LC_{50}) values range from 0.2 to 0.4 mg/ml for *Penicillium notatum, Aspergillus flavus, and A. niger and Mucor hiemalis.* Vernodalol showed moderate inhibitory activity against *A. flavus*, *A. niger* and *P. notatum* with (LC_{50}) value of 0.3, 0.4, and 0.5 mg/ml respectively (Erasto et al. 2006).

Natural compounds effectively controlling plant pathogens and pests are represented by a diversity of substances belonging to different chemical classes and produced by a wide range of living organisms. Proteins are abundant and ubiquitous natural compounds strongly associated with all living organisms, hence it is possible to believe their involvement in plant protection.

4.3.2 Proteins as Biopesticides

Proteinaceous compounds are important constituents of plant immune system and take part in natural plant defense against pathogens; their plant protection potential is harnessed since long time by scientist.

The compounds synthesized by formulated biocontrol agents interact with pathogenic microflora or induce resistance in plants. Constitutive or inducible expression of protein encoding genes transferred into plants confer them resistance to many economically important diseases.

Biopesticides based on microbial peptides or transgenic plants carrying genes of defensins, lectins and proteinase inhibitors are good tools for the fight against pest of plants. Peptides have advantages over more elementary organic antimicrobial compounds when used for plant protection, because the peptide molecule contain 10–50 or even more at times (up to 85) amino acid residues, they can more specifically interact with their protein targets in causative agents (Park et al. 2009).

Biopesticidal peptides can work against pathogens by inhibiting nucleic acid and proteins biosyntheses and enzyme activity or by interacting with plasma lemma and destroying its integrity (Huang 2000).

4.3.3 Essential Oils

Essential oils are volatile, natural, complex compounds characterized by a strong odour and are formed by aromatic plants as secondary metabolites. The secondary metabolites can be classified into three major heads:

(i) Isoprenoids
(ii) Aromatic compounds
(iii) Alkaloid components

They are liquid, volatile, limpid and rarely colored, lipid soluble and soluble in organic solvents with a generally lower density than that of water. They can be synthesized by all plant organs, i.e. buds, flowers, leaves, stems, twigs, seeds, fruits, roots, wood or bark, and are stored in secretory cells, cavities, canals, epidermic cells or glandular trichomes.

Essential oils are very complex natural mixtures which can contain about 20–60 components at quite different concentrations.

The general antifungal activity of essential oils is well documented (Meepagala et al. 2002) and there have been some studies on the effects of essential oils on postharvest pathogens (Alpsoy 2010). These essential oils are thought to play a role in plant defense mechanisms against phytopathogenic micro-organisms. The various oils were tested against *A. flavus* and *A. parasiticus* by different workers (Reddy et al. 2010). Thanaboripat et al. (2007) studied the effects of 16 essential oils from aromatic plants against mycelia growth of *A. flavus* IMI 242684. The results showed that the essential oil of white wood (*Melaleuca cajeputi*) gave the highest inhibition followed by the essential oils of cinnamon (*Cinnamomum cassia*) and lavender (*Lavandula officinalis*), respectively. In the *in vitro* studies Jardim et al. (2008) reported antifungal activity of essential oil from the Brazilian epazote (*Chenopodium ambrosioides* L.) evaluated by the poison food assay at concentrations of 0.3, 0.1 and 0.05 % against postharvest deteriorating fungi (*A. flavus*, *A. glaucus*, *A. niger* and *A. ochraceous*). Kumar et al. (2009) studied the efficacy of essential oil from *Mentha arvensis* L. to control storage moulds of Chickpea. The oil effectively reduced mycelia growth of *A. flavus*. Kumar et al. (2010) studied the efficacy of *O. sanctum* essential oil and found efficacious in checking growth of *A. flavus* and also inhibited the aflatoxin B1 production completely at concentration of 0.2 and 0.1 μg mL^{-1}, respectively. Similarly the effect of oils of was tested against other storage fungi enumerated in Table 2.

In vitro efficacy of citrus oil against *A. niger* was tested by Sharma and Tripathi (2006) *Citrus sinensis* essential oil caused complete growth inhibition of *A. niger* on agar plates. Higher concentration of oil was found to be lethal. The oil showed fungistatic activity at low concentration. The essential oil significantly reduced the growth of *A. niger* in a dosage response manner (Sharma and Tripathi 2008). *Citrus sinensis* is a result of attack of oil on the cell wall and retraction of cytoplasm in the hyphae and ultimately death of the mycelium. Scanning electron micrograph reveals the mechanism of action of oil (Fig. 7).

The biological activity attributed to the action of oils could be cytotoxicity, phototoxicity, nuclear mutagenicity and cytoplasmic mutagenicity of the oil components (Bakkali et al. 2008).

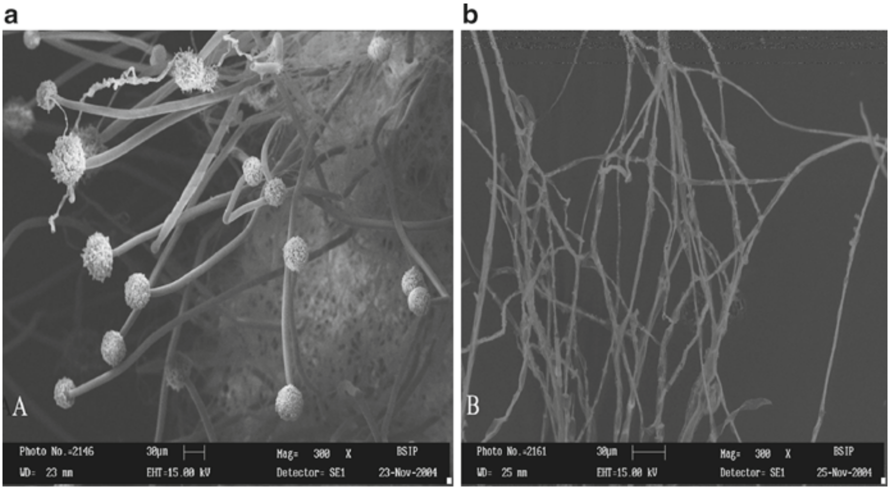

Fig. 7 Scanning electron micrograph of fungal hyphae of *Aspergillus niger*. (**a**) Control with normal heads, (**b**) Sample treated with citrus essential oil showing no head formation

Srivastava et al. (2008) concluded that, in general, the inhibitory action of natural products on fungal cells involves cytoplasm granulation, cytoplasmic membrane rupture and inactivation and/or inhibition of synthesis of intracellular enzymes.

Target storage fungi	Plant species
Aspergillus flavus *A. parasiticus*	*Chenopodium ambrosiodes Cymbopogon flexuosus,C. martini Eucalyptus globules* *Eupatorium cannabinum* *Lavandula officinalis* *Mentha arvensis* *Ocimum canum* *Vetiveria zizanoides*
Aspergillus ochraceus *Penicillium verrucosum* *P. brevicompactum*	*Coriandrum sativum* *Mentha arvensis* *Ocimum basilicum* *Salvia officinalis* *Orgianum vulgare*
Fusarium oxysporum *F. moniliforme* *F. nivale* *F. semitectum* *F. proliferatum* *F. verticillioides*	*Azadirachta indica* *Brassica campestris* *Chenopodium ambrosioides* *Ferula asafetida* *Hypericum linarioides* *Nigella sativa* *Ocimum gratissimum* *O. basilicum* *Silene armeria*

4.4 Biotechnological Methods

4.4.1 Contribution of Molecular Biology in the Development of Alternatives of Synthetic Chemicals

Natural products are chemical compounds of biological origin and are extracted from secondary metabolites of microorganisms, plants and animals. They have pharmaceutical applications in pest and disease management in agronomy. Natural products have a broad range constituting of natural antioxidants, bioflavours, biopreservatives, natural colorings, fragrances and microbial polysaccharides. In present scenario we have to apply this technology in pest management. The natural products should replace the synthetic chemicals in field of agriculture as in the similar manner in cosmetics and food industries. Molecular biology a boon in biological science has overcome in all the difficulties of human life.

4.4.2 Role of Biotechnology in Identification of Natural Product

The biotechnological tools available for systematics are protein profiles, polysaccharides, plasmids, DNA-DNA hybridization, various PCR based techniques and DNA sequencing and alignment. With the resistance of bioinformatics, the molecular data are processed and phylogenetic relationships are generated. This facilitates the search for better performer within producers of known products. Plant tissue culture and cell culture techniques are able for the clonal propagation of plants within a short period of time in a small area. Similarly regenerated plants through micro-propagation are extremely important to relieve the pressure on the wild plants exerted by over exploitation. As mentioned in the review by Chaturvedi et al. (2007), the micro-propagation and field establishment of *Dioscorea floribandu* in India has been a success story. They calculate the number of plantlets that could be obtained within a year starting from a single nodal cutting as 2,560,000 in comparison to a maximum of ten plants from a single tuber which can be obtained within 3 years of growth in the fields.

The only other compound produced using plant cell culture that has successfully entered the market is ginseng saponin originated from *Panox ginseng*. Further improvements to the yields have been shown in hairy root cultures fed with specific nitrogen and phosphorus sources (Jeong and Park 2006).

Therefore, our target is to explore more natural product resources not only explore but also exploit them for preparing formulation and use against storage biodeteriogens. Biotechnological tools will also be beneficial to bring the natural formulation from lab to land. Thus, the objective of rejecting the synthetic chemicals and application of natural products will be fulfilled which is the need of the hour.

4.4.3 Genetically Engineered Resistant Varieties as Alternatives to Synthetic Chemicals

In view of the hazardous effects of mycotoxin, insects, rust, smuts efforts are being made to develop mould resistant varieties which will be mould free not only in fields as standing crops but also during storage. Virtually all crops improved with transferred DNA (often called GM crops or GMOs) to date have been developed to aid farmers to increase productivity by reducing crop damage from weeds, diseases or insects. Recombinant DNA technology has been a very useful tool in this direction. The strategy aims to prevent mycotoxin biosynthesis, or to detoxify mycotoxins in plants, creating transgenic lines with genes that code for instance for enzymes that degrade mycotoxins (Duvick 2001). Transgenic wheat expressing the *Arabidopsis NPR1* gene, a gene that regulates defense responses, was shown to exhibit a high level of resistance to FHB in greenhouse evaluations (Makandar et al. 2006). Ribosome-inactivating proteins are plant enzymes that have 28S rRNA *N*-glycosidase.

Tools like molecular markers can be very useful in plant breeding experiments; Traditional breeding involves selection of individual plants based on visible or measurable traits. By examining the DNA, scientists can use molecular markers to select plants that possess a desirable gene, even in the absence of a visible trait. International Institute of Tropical Agriculture has used molecular markers to obtain cowpea resistant to bruchid (a beetle), disease-resistant white yam and cassava resistant to Cassava Mosaic Disease, among others. Molecular diagnostics are used in agriculture to more accurately diagnose crop diseases.

Further studies are required in relation to physiological and biochemical characterization, genetic mapping, plant transformation using resistance associated protein gene (RAP gene), gene silencing experiments and marker associated breeding in order to develop preventive control measures.

5 Plant Products in Pest Management

The term allelochemical (from Geek allelon: 'one another') is used to describe the chemicals involved in interspecific interactions. It is defined as a chemical significant to organisms of a species different from its source. Allelochemicals are divided into four subgroups, depending on whether the emitter, receiver, or both benefit in interaction.

Allomone is an allelochemical which is a natural plant metabolite safe for health and environment, having specific effects on individual pest species, prevent the development of pest resistance. Allomone are categorized in three sub groups as repellents, anti-ovipositants, antifeedants but major research has been focused on antifeedants which is a topic of major interest.

Due to not only showing above mentioned properties but other biological effects such as growth inhibition, mortality and reduced fertility of surviving individuals which increase the practical efficiency of the products (Koul 2005).

Some products that primarily contain substances with an insecticide effect and at the same time also show an antifeedent and anti-oviposition effect are used at present. *Azadirachta indica* has been well known in India and neighboring countries for more than 2,000 years as one of the most versatile medicinal plant, having a wide spectrum of biological activity.

The repellent activities including host deterrence and anti-oviposition of pongam oil (*Pomgamia pinnata*) against the adults of the common green house whitefly *Trialeurodes vaporariorum* westwood were tested in greenhouses (Pavela and Herda 2007).

Nevertheless the use of antifeedents in pest management programs has enormous appeal. They satisfy the need to protect specific crops while avoiding damage to non target organisms, so the potential value is great.

Plant derived compounds as natural product represents vast and rapidly progressing resource. These are botanical fungicides which are best suited for use in industrialized when strict enforcement pesticide regulations are impractical, or in the case of organic production. However they can play a much better role in protecting food products in developing countries where synthetic chemicals poisoning are most prevalent.

Effort should be made to search for indigenous plants as a source of pesticides compounds and to bioprospect the pesticidal properties of these plant products.

6 Conclusion

Ever since man started the practice of crop cultivation to meet his food requirements, he has been effortful to protect the harvest from enemies and deterioration, and to safely store it for ensuring an abundant continuous supply. This practice of sophisticated, systematic bulk storage of grains in granaries dates back to Natufian period and the “Great Granary” of the Indus Valley civilization needs no introduction.

To prevent biodeterioration of cereals Good Agricultural Practices should be used to facilitate stored commodities to be effectively conserved with minimum loss in quality. These include accurate and regular moisture measurements, efficient and prompt drying of wet cereals, storage in hygienic environment and proper monitoring in storage. Need of the hour is to strengthen traditional means of storage with modern inputs and to invest in construction of scientific warehouses so as to prevent enormous storage losses. Natural fungal contamination can be minimized in field and in storage by application of genetic and molecular approaches, biocontrol agents, essential oil and irradiation. Work is in progress to further develop and commercialize cost effective technologies. Additionally, all the biocontrol agents or genetically modified organisms that are planned to be developed for the control of fungi have to pass all the bio-safety tests in order to be safe for the consumers. Current research also needs to integrate the existing sound control measures and develop strategies to prevent spoilage of grains and mycotoxins entering the human and animal food chains.

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Allelopathy for Pest Control

Kambaska Kumar Behera and Renu Bist

Abstract Plants are attacked by a plethora of pathogens or pests. Pest attack in turn induces or enhances the synthesis of a many chemical 'weapons' produced by plant defenses. These chemicals are classified broadly into nitrogen compounds, terpenoids and phenolics. They have a broad range of antifungal, antimicrobial and pesticidal activities. Thus, these plant chemicals can be extracted and further used as efficient biopesticides or microbicides. They are eco-friendly due to their ephemeral nature. Unlike many synthetic pesticides that often have harmful side effects and long residual time, allelochemicals are biodegradable fast.

Plants produce many types of secondary metabolites – listed in Table 1 – including resins, phenolic acids, amino acids and essential oils, which can be used to manage pests. We review crop allelopathic activity to suppress weeds, microbes and insects. We present benefits of biotechnological methods of extraction and use of allelochemicals. The essential oils of medicinal plants such as thyme, oregano, rosemary, lavender, fennel and laurel have fungitoxic effects against foliar and soil-borne plant pathogenic fungi. Natural miticides are an alternative to synthetic miticides because they have low toxicity in mammals, little environmental effect and wide public acceptance. Therefore essential oils have the potential for use in the control of many pests such as a mite *Tetranychus cinnabarinus*.

Keywords Allelochemicals • Biopesticide • Disease • Pest management • Chemical pesticide • Environment • Toxicity • Miticides • Antimicrobial • Agricultural

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List of Abbreviations

Avr	avirulence genes
HCN	cyanohydric acid
PCD	programmed cell death
PPO	polyphenol oxidase
PR	pathogenesis-related genes
QTL	quantitative trait loci
R	resistance

1 Introduction

Like animals, plants do have to fight with a plethora of problems for their very survival. Both biotic and abiotic factors affect plant survival. The major biotic stresses are caused by a wide variety of pathogens that include bacteria, viruses, fungi, nematodes, insects and many herbivorous animals. Being sessile, plants have developed an array of sophisticated innate defense system against the microbial invaders in consequence of the long process of host-pathogen co-evolution (Dodds and Rathjen 2010).

The multiple layers of defense mechanisms evolved by plants ranges from passive-mechanical or preformed chemical barriers, which provide nonspecific/non-host protection (Tyler 2001; Yun and Loake 2002), to active responses that provide host- or cultivar-specific resistance (Jackson and Taylor 1996; Hammond-Kosack and Parker 2003). Passive-mechanical barriers include the various structural features that are characteristic of different plants like thorns, prickles, spines or trichomes, many of these may sometimes also contain irritants or poisons. In addition to these structures, other mechanical barriers to microbial invasion include the waxy outer layer called cuticle, the secondary protective tissue namely the periderm in addition to wax, resins, latex (Agrawal and Konno 2009), lignins etc. that prevent pathogen ingress (Fig. 1). Many plants have non-protoplasmic inclusions primarily in epidermal cells like calcium oxalate crystals (Goldblatt et al. 1984; Rudall and Caddick 1994), starch grains, mucilage (slime) and silica bodies (10–30 μ), which serve as variety of purposes including structural rigidity (Kaufman et al. 1979; Christina et al. 2003), lodging resistance (Ma et al. 2006), mechanical resistance to invading organisms (Namaganda et al. 2009), tolerance to pathogens (Djamin and Pathak 1967) and also to overcome various abiotic stresses like drought, radiation, nutrient imbalance, temperature fluctuations and osmotic imbalances (Hodson et al. 2005; Ma and Yamaji 2006). Pathogen can overcome these physical barriers by way of force penetration using specialized structures, entry through stomata or wounded regions or by production of degradative enzymes (Walton 1994). Since plants produce a wide range of secondary metabolites and many of which posseses antimicrobial activities, the pathogen will be encountered by this second line of defense systems (Table 1) (Edreva et al. 2008).

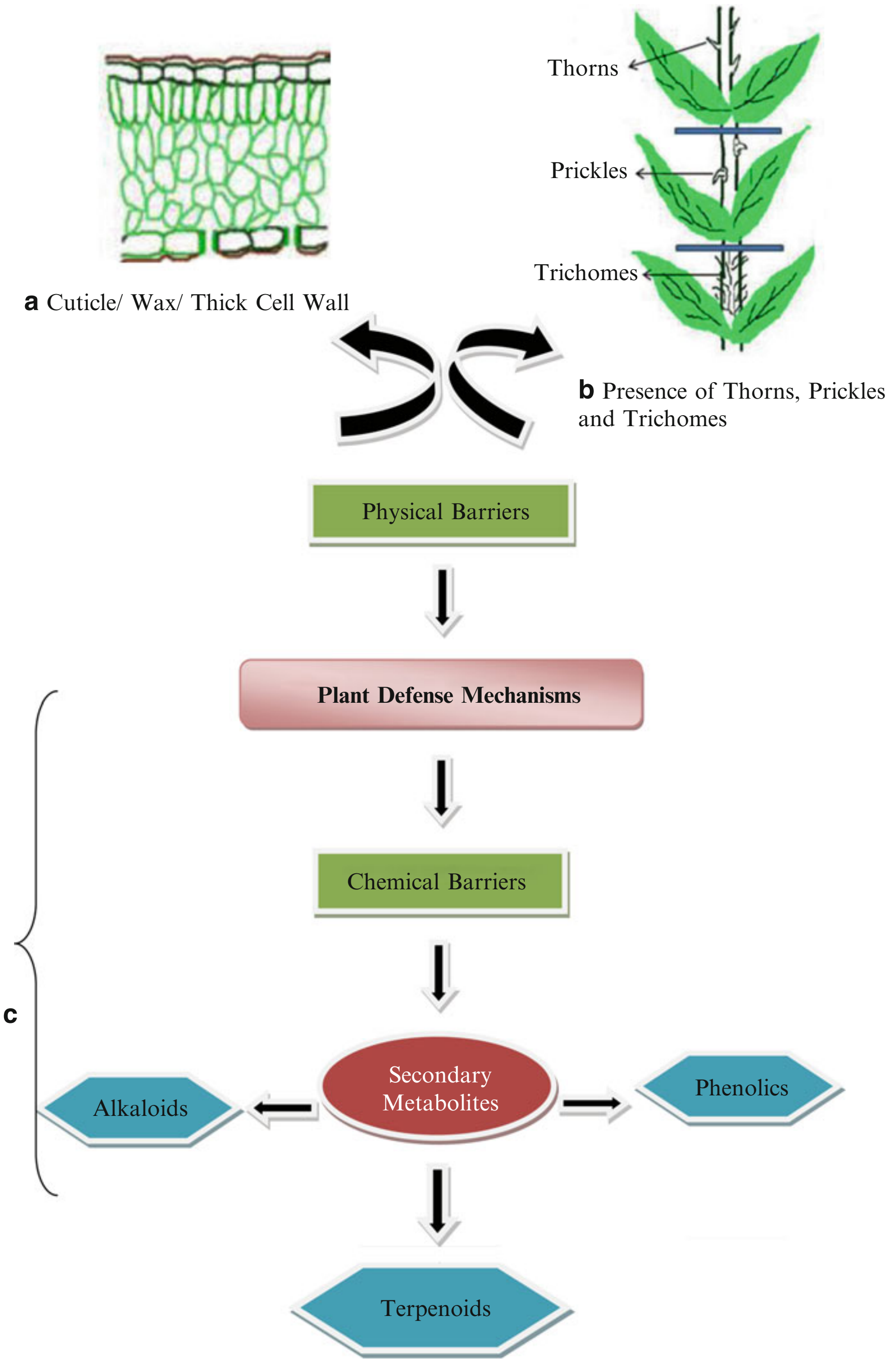

Fig. 1 Different types of defense mechanisms in plants. (**a**) Anatomical barriers; (**b**) Physical barriers; (**c**) Sequential defense mechanism

Table 1 Various allelochemicals, their plant source and target pest against which they show their activity

Sl. No.	Plant name	Principal compound	Target pest	Reference
1	*Origanum onites* L	Carvacral	*Tetranychus cinnabarinus*	Sertkaya et al. (2010), Soylu et al. (2006)
2	*Thymbra spicata* L	Carvacral	*Tetranychus cinnabarinus*	Sertkaya et al. (2010)
3	*Lavendula stoechas* L	α-thujone and carvone	*Tetranychus cinnabarinus*	Sertkaya et al. (2010), Soylu et al. (2007)
4	*Mentha spicata* L	α-thujone and carvone	*Tetranychus cinnabarinus*	Sertkaya et al. (2010)
5	*Oryza sativa* L	Phenolic acids	*Heteranthera limosa, Ammannia coccinea*	Chung et al. (2001, 2006), Dong et al. (2005), Field et al. (2006), Prasanta and Bhowmika (2003)
6	*Triticum aestivum* L	Phenolic acids and hydroxamic acids	*Ammannia coccinea*	Barnes and Putnam (1987), Perez and Ormeno-Nunez (1991), Wu et al. (2001)
7	*Secale cereale* L	Phenolic acids and hydroxamic acids	*Sida spinosa* L., *Portulaca oleracea* L., *Xanthium strumarium* L., *Ipomaea* spp., *Cassia obtusifolia* L	Barnes and Putnam (1987), Pérez and Ormeño-Núñez (1991), Wu et al. (2001)
8	*Avena sativa* L	Scopoletin, various phenolic acids and amino acid	*Phalaris minor*	Fay and Duke (1977), Sánchez-Moreiras et al. (2004)
9	*Sorghum bicolor* (L.) Moench	Sorgoleone	*Phalaris minor*	Czarnota et al. (2001), Yang et al. (2004), Dayan (2006), Field et al. (2006)
10	*Zea mays* L	Phenolic acids and hydroxamic acids	*S. hermonthica*	Khan et al. (2000)
11	*Azadirachta indica* A. Juss	Azadirachtin	*Taeniothrips sjostedti, Heliothis armigera*	Hongo and Karel (1986)
12	*Lycopersicon esculentum* L.	Phenolic acids and hydroxamic acids	*Taeniothrips sjostedti, Heliothis armigera*	Hongo and Karel (1986)
13	*Capsicum annuum* L.	Phenolic acids and hydroxamic acids	*Taeniothrips sjostedti, Heliothis armigera*	Hongo and Karel (1986)

These defensive secondary metabolites in plants can be classified as terpenoids, phenolics and nitrogen compounds (Harborne 1999). The chemical barrier has evolved as a consequence of natural selection and plays decisive role in plant resistance against the invading microbes (Ingham 1973; Osbourn 1996). However, pathogens also evolve themselves to overcome this chemical arsenal by acquiring various types of abilities (Morrisey and Osbourn 1999; Papadopoulou et al. 1999). Once the pathogen breaches the preformed mechanical barriers it comes under the robust surveillance of host resistance/active defense which finally results in resistance or susceptibility of host to the invading pathogen (Jones and Jones 1997; Hammond-Kosack and Jones 1997; Moffett et al. 2002; Morita-Yamamuro et al. 2005).

In resistant plants, pathogen avirulence (*Avr*) gene encoded elicitors (Dangl and Holub 1997; Nimchuk et al. 2001) are perceived by the plant *R*-gene encoded receptors that “guard” the host proteins (Dangl and Jones 2001; Jones 2001; Rathjen and Moffet 2003). This molecular recognition originally proposed by Flor (1956, 1971) and elaborated in the “gene-for-gene model” underlies the molecular basis of defense response and subsequently triggers a hierarchy of defensive molecular events in the plant. After Flor’s classic work, it became evident that the outcome of many host-parasite interactions is governed by matching gene pairs [resistance (*R*) and avirulence (*Avr*) genes, respectively] (Crute and Pink 1996). R-proteins localized in the plasma membrane or cytoplasm impart resistance to the host plant either by direct detection of elicitors or indirectly through detection of any pathogen mediated alterations to the “guarded” host proteins (Dangl and Jones 2001). Following the *R-Avr* gene product interaction, a signaling cascade is activated that includes generation of reactive oxygen intermediates (ROIs), transient ion fluxes, intracellular pH changes, cell wall strengthening, release of secondary signaling molecules like nitric oxide (NO), salicylic acid, jasmonic acid and ethylene and activation of MAPK (Mitogen activated protein kinase) cascades (Martin 1999; McDowell and Dangl 2000; Heath 2000). All these molecular events eventually result in the transcriptional activation of batteries of plant defense genes, such as pathogenesis-related (*PR*) genes. The cumulative effect of all these cellular events arrests microbial proliferation through collapse of challenged plant cells by a localized programmed cell death (PCD), termed the ‘hypersensitive response’ (Keen et al. 1993) and shares analogy to animal apoptosis (Lam et al. 2001). Hypersensitive response results in establishment of systemic acquired resistance (Ross 1961) that immunizes the entire plant against secondary attack by a broad spectrum of pathogens (Ryals et al. 1996). Systemic acquired resistance is characterized by an increase in endogenously synthesized signaling molecules like salicylic acid (Malamy et al. 1990; Metraux et al. 1990), concomitant activation of *PR* genes (Bol et al. 1990; Ward et al. 1991) and heightened plant resistance (Staskawicz et al. 1995). Other signaling molecules like jasmonic acid and ethylene have also been observed to induce expression of defense genes (Wasternack and Parthier 1997; van Wees et al. 2000; Hammond-Kosack and Parker 2003) that are not activated by salicylic acid (Penninckx et al. 1996). Apparently it has been proven that jasmonic acid/ethylene act antagonistically to salicylic acid pathway but global gene expression profiling supports existence of substantial cross-talk between the salicylic acid, jasmonic acid and ethylene signaling pathways (Glazebrook et al. 2003; Schenk et al. 2000; Thomma et al. 2001). The defense genes activated by these secondary signaling molecules include proteases (Pechan et al. 2000), protease inhibitors (Azarkan et al. 2004; Kehr 2006; Walz et al. 2004), chitinases (Howard and Glazer 1969; Azarkan et al. 2004; Kim et al. 2003), oxidases like polyphenol oxidase (PPO), peroxidase (Saby et al. 2003) and lipoxygenases (Walz et al. 2004) in addition to phosphatase (Lynn and Clevette-Radford 1987) and lipases (Gandhi and Mukherjee 2000).

2 Chemical Defense in Plants

Among the many different mechanisms employed by plants for combating diseases, the ability to synthesize an arsenal of low-molecular weight volatile and non-volatile chemicals helps them to interact with the ever-changing physical environment (Firn and Jones 2009). These defensive organic compounds called secondary metabolites have been a major counter defense tactics evolved by plants to withstand pathogen attack (Boller 1995). Unlike primary metabolites which are found in every dividing cell, secondary metabolite biosynthesis is regulated by environmental factors, genotype of the plant as well as age (Kossel 1991). There is also difference in distribution with particular metabolites being confined to phylogenetically related taxa while others having much broader distribution (Futuymaa and Agrawal 2009; Dixon 2001). Even in any particular plant the distribution of secondary metabolites may not be uniform but it will be constitutive with an induction seen in response to pathogen attack (Zong and Wang 2006). Constitutive/basal distribution of secondary metabolites, which is central to the optimal defense theory of plant-pathogen interactions (McKey 1979; Rhoades 1979; Strauss et al. 2002; Holland et al. 2009), is of significance considering the crucial role of speed of the host response in determining resistance to the invading pathogen.

Plants mainly produce three kinds of secondary metabolites that are nitrogen compounds, terpenoids, and phenolics (Harborne 1999). Table 2 represents different physical and chemical barriers which are present as barriers against certain pests, herbivory and other harmful effects. Current review emphasizes on chemical defence mechanism of plants against various target pests. The nitrogen compounds include alkaloids, cyanogenic glycosides and glucosinolates. Alkaloids widespread among different plant taxa are derived from various amino acids and are basic organic compounds with heterocyclic nitrogen, the position of which varies according to the plant families (Harborne 1993; Wink 2004). More than 12,000 different types of alkaloids have been discovered from over 300 plant families (Zwenger and Basu 2008). The defensive effects of alkaloids are manifested by their ability to affect cell membrane/cytoskeletal structure, as inhibitors of glycosidases and sugar-metabolizing enzymes (Asano et al. 2000) or by inhibition of protein/DNA synthesis (Schmeller et al. 1997). Cyanogenic glycosides composed of an alpha-hydroxynitrile type aglycone and sugar moiety (mostly D-glucose) are stored in inactive forms in plant vacuoles among a wide range

Table 2 Summary of the various mechanical and chemical defense systems as barriers in plants

Pre-formed defenses	Type/nature	Mode of action	Examples	Reference
Physical barriers				
Structural features	Thorns, prickles, spines, trichomes, thick cell wall etc	Deterrents to invading organisms	Thorns on the stem of raspberry plant, serve as a mechanical defense against herbivory	Fernandes (1994)
Physiological features	Wax, cuticle, latex, resins, silica bodies, crystals and other inclusions	Inhibits/interferes with pathogen attack	Silicification in grass leaves, *Larrea tridentate* resin serves as an antidessicant, solar radiation filter and also as a herbivore deterrent	McNaughton and Tarrants (1983), Rhoades (1977)
Chemical barriers: Secondary metabolites				
Nitrogen compounds	Alkaloids	Alters the metabolic system of the invading organism, Enzyme inhibition	Aporphine alkaloid liriodenine from, *Liriodendron tulipifera* against *Candida albicans*	Clark et al. (1987)
	Cyanogenic glycosides		Cyanogenic glycosides of *Sorghum bicolor* impart resistance to *Locusta migratoria*	Woodhead and Bernays (1987)
	Glucosinolates		Glucosinolate breakdown products negatively affects insect respiratory system	Clauss et al. (2006), Muller et al. (2001)
Terpenoids	Isoprene units	Inhibits enzymes, Membrane disruption, as pathogenic deterrents, pollinator attractants, plant-plant signaling	Monoterpenes like pyrethroid from *Chrysanthemum* spp.; alpha pinene and myrcene from *Pinus* spp., carvone from *Carum carvi* with fungicudal activity	Ikeda et al. (1980), Raffa et al. (1985), Hartmans et al. (1995)
			Diterpenes like abietane and seco-abietane from *Salvia prionitis*	Chen et al. (2002)
			Sesquiterpenes confer resistance to Colorado potato beetle in tomato	Carter et al. (1989)

(continued)

Table 2 (continued)

Pre-formed defenses	Type/nature	Mode of action	Examples	Reference
Phenolics	Tannins	Membrane destabilization, Antioxidant, inhibition of microbial enzymes, inactivation of microbial adhesins	Catechol (I) and protocatechuic acid (II) accumulation in onion scales imparts resistance to *Colletotrichum circinans*; lignans in disruption of endocrine system	Link et al. (1992)
	Lignans			Harmatha and Dinan (2003)
	Phenolic acid			Wallis et al. (2008), Bonello et al. (2006)
	Flavanoids			Treutter (2006)

of plant taxa (Vetter 2000). Upon enzymic hydrolysis, cyanogenic glycosides release cyanohydric acid (HCN) or prussic acid (Harborne 1993) which is extremely toxic to a wide spectrum of organism due to its ability to chelate metal ions functioning as co-factors to many key enzymes involved in metabolic processes (McMahon et al. 1995; Francisco and Pinotti 2004). In the unaffected plant the enzyme and cyanogenic glycosides remain separate and are brought in contact upon pathogen attack (Gruhnert et al. 1994). Sulfur containing glucosinolates or thioglucosides produced widely by plants belonging to the genera *Cruciferae* have well-documented antimicrobial activity (Fenwick et al. 1983). Hydrolysis of glucosinolates liberates D-glucose, sulphate ion and a series of compounds such as isothiocyanate, thiocyanate and nitrile that posseses fungitoxic activity (Mithen 1992; Wink 2004).

Most numerous and structurally diverse group of organic secondary metabolites are terpenoids (isoprenoids) derived from five carbon isoprene units and having diverse physiological, metabolic and structural functions in addition to their significant role in plant defense (Rees and Harborne 1985; Sessa et al. 2000; Dussourd 2003). All terpenoids are derived by isomerization of isopentenyl diphosphate to dimethylallyl diphosphate by isopentenyl diphosphate isomerase. Isopentenyl diphosphate and dimethylallyl diphosphate originate from either the plastidial methyl-erythritol 4-phosphate pathway or the cytosolic mevalonate pathway (Chappell 1995; Bochar et al. 1999). Dimethylallyl diphosphate condenses with one, two or three units of isopentenyl diphosphate catalyzed by prenyltransferases to give geranyl diphosphate, farnesyl diphosphate, and geranylgeranyl diphosphate respectively. These three acyclic prenyl diphosphates are converted by a very large group of enzymes called the terpene (terpenoid) synthases to corresponding monoterpenoid (C10), sesquiterpenoid (C15), and diterpenoids (C20). Subsequent hydroxylation and oxidation of terpenes catalyzed by cytochrome P450 enzymes further diversifies the terpenes (Zulak and Bohlmann 2010). Gene duplication and neofunctionalization of the enzymes that synthesize and subsequently modify terpenes are primarily responsible for the terpenoid diversity in response to different physiological conditions (Keeling et al. 2008; Trapp and Croteau 2001).

Phenolics with a wide distribution in the plant kingdom are aromatic compounds with hydroxyl groups. Phenolics range from simple plant phenols like hydroxybenzoic acid to phenylpropanoids and complex phenyl propanoids like flavonoids that give pigmentation to plants and constitute a complex group called tannins (Harborne 1993). Flavanoids are further sub-divided as flavanols, anthocyanidins and chalcones and perform a wide range of biological activities that includes their role as attractants or feeding deterrents (Snook 1994), biotic and abiotic stress protective agents (Tattini et al. 2004; Moore et al. 2005; Schlösser 1994; Inderjit and Gross 2002). Antimicrobial activities of flavanoids are mediated by their ability to inhibit microbial cell wall degrading enzymes and chelation of metals necessary for enzyme activity (Skadhauge et al. 1997). Phenolics generally have antioxidant properties and are thus of therapeutic significance (Dai and Mumper 2010). Systemic induction and accumulation of low molecular weight phenolics and phenolic polymers like lignin and suberin is observed in response to various diseases (Bonello et al. 2006; Wallis et al. 2008; Cvikrova et al. 2006). Inhibition of pathogen colonization by phenolics is mediated via protein precipitation and iron depletion (Scalbert 1991).

3 Molecular Evolution of Allelochemical Diversity

Secondary metabolite chemistry of plants is dynamic and subject to changes depending on the type of environmental stress (Kliebenstein 2004; Hammerschmidt 2005; Mary Ann Lila 2006) with upregulation of key genes observed in response to pathogen attack (Baldwin 1998; Sirvent and Gibson 2002). Pathogen attacks impose natural selection on plants to evolve defensive strategies (Agrawal 2007) that in turn depends on the plants life history, genetic attributes and mating pattern (Futuymaa and Agrawal 2009; Johnson et al. 2009). Reduced recombination and allelic segregation as a consequence of prolonged asexual reproductive strategies negatively affects defense gene evolution as proposed in the Recombination-Mating hypothesis (Levin 1975). It is hypothesized that asexual reproduction not only results in erosion of genetic variation but also is susceptible to Muller's Ratchet according to which sexual reproduction purges the deleterious mutations that might affect primary or secondary metabolic processes (Muller 1964; Paland and Lynch 2006). As per the Red Queen hypothesis, maintenance of sexual reproduction is of prime significance in the host-pathogen co-evolutionary arms race (Jaenike 1977), thereby equipping plants to synthesize an enormous reservoir of natural chemical diversity (Agrawal 2007). Natural selection pressures will select for alleles that enhance or retain secondary metabolite diversity taking into consideration the fitness cost on the plant (Agrawal and Fishbein 2008). Phylogenetic analysis has revealed the role of recombination, mutations, gene duplications and reshuffling in maintaining allelic diversity in the secondary metabolite as well defense genetic pool (Wagner 1998; Gierl and Frey 2001; Kondrashov et al. 2002). Molecular studies in genes associated with secondary metabolite biosynthesis like polyketide synthases (PKS), genes associated with phenyl propanoid (Milkowski and Strack 2004; Stehle et al. 2006) and alkaloid (Ober and Hartmann 1999) biosynthetic pathway, cytochrome P450 (Scott and Wen 2001) and terpene synthases (Bohlmann et al. 1998; Rohdich et al. 2005) have revealed that environmental selection pressures must have favored duplication followed by functional divergence in generating/maintaining a rich diversity of metabolites that are distinguishable from their biogenetic starter units. Studies have indicated that terpenoid phytochemical complexity is contributed by a multitude of phylogenetically diverse terpene synthases and cytochrome P450 that have been subject to repeated duplication and divergence (Zulak and Bohlmann 2010). Even single amino acid changes have been observed to alter substrate specificity, product profiles and kinetic efficiency of these enzymes (Jez et al. 2002; Keeling and Bohlmann 2006). Nucleotide sequence diversity analysis of such functional genes from resistant and susceptible sources have thus provided a framework for understanding the variations in deployment of metabolites and defensive proteins in plant-pathogen responses (Shonle and Bergelson 2000; Bishop et al. 2000).

Secondary metabolite biosynthetic genes can also evolve by divergent evolution and by domain swapping (O'Brien and Herschlag 1999; Schmidt et al. 2003; Katoh et al. 2004). Simultaneous analysis of diversity at both neutral and defense-related functional loci has helped in elucidating the evolutionary forces shaping resistance evolution (Burdon and Thrall 1999; de Meaux et al. 2003). Adaptive evolution at key residues involved in detection of variable pathogen ligands and recombination events generating paralogues have been suggested as primary mechanisms responsible for generation of diversity at these loci (Ehrlich and Raven 1964; Michelmore and Meyers 1998; Futuymaa and Agrawal 2009). Besides sequence diversity analysis have also revealed the role of balancing selection in maintaining high nucleotide diversity levels at key resistance loci reflecting “trench warfare” (Stahl et al. 1999) or “recycling polymorphism” (Holub 2001) between host-pathogen genotypes (Bergelson et al. 2001).

Unfortunately, domestication and breeding procedures have eliminated many of the genes responsible for the biosynthesis of secondary metabolite in crop plants (Lebot et al. 2005; Olsen and Gross 2008). As a result, the dependence on chemical pesticides/insecticides increased considerably (Holdren and Ehrlich 1974; Nash et al. 2010). This increased susceptibility in cultivars attributed to “domestication bottleneck” eventually reduces overall genetic diversity in the cultivars as against their resistant wild counterparts (Tang and Knapp 2003). Hence to gain a comprehensive understanding of the molecular processes governing host-pathogen interactions, diversity should also be sampled in genes involved in secondary metabolite biosynthesis of both cultivars as well in the relatively undisturbed wild relatives of crop plants (Hawkes 1977). The adverse impact of pesticides on environment and biodiversity is compounded by the susceptibility of cultivars of many crop plants. It has sparked an interest in understanding the mechanisms underlying the evolution and nature of this chemical diversity in developing biologically and ecologically friendly sustainable resistance strategies by making use of the plants own innate immune system.

4 Allelochemicals as Biocontrol Agents for Plant Diseases

Growing global awareness about safe food and increasing public consciousness on the adverse impact of pesticides both on human health and environment has witnessed a boom in organic farming and has fuelled the search for greener alternatives in the agricultural sector (Fravel 2005; Slusarenko et al. 2008). Plant derived allelochemicals or secondary metabolites provide better alternatives than pesticides because of low toxicity, biodegradability and hence reduced risk to environment and human health (Tesar and Marble 1988; Jespers and de Waard 1993; Tripathi and Dubey 2004) and thus serve as leads for new agrochemicals. Allelochemicals produced from a plant source show leaching in the soil, due to precipitation and other factors. There they interact with different soil components and affect the quality of soil in many ways. One among these is the biocontrol of various plant diseases. Leached out allelochemicals and their exudates then enter the groundwater and may be transpored to distant areas where they affect the growth and physiology of receiver plants (Fig. 2). In this way, phytotoxic activity of an allelochemical is influenced by soil factors and plant factors of donor and receiver plants both. While plant factors and soil factors are ultimately affected by meteorological factors.

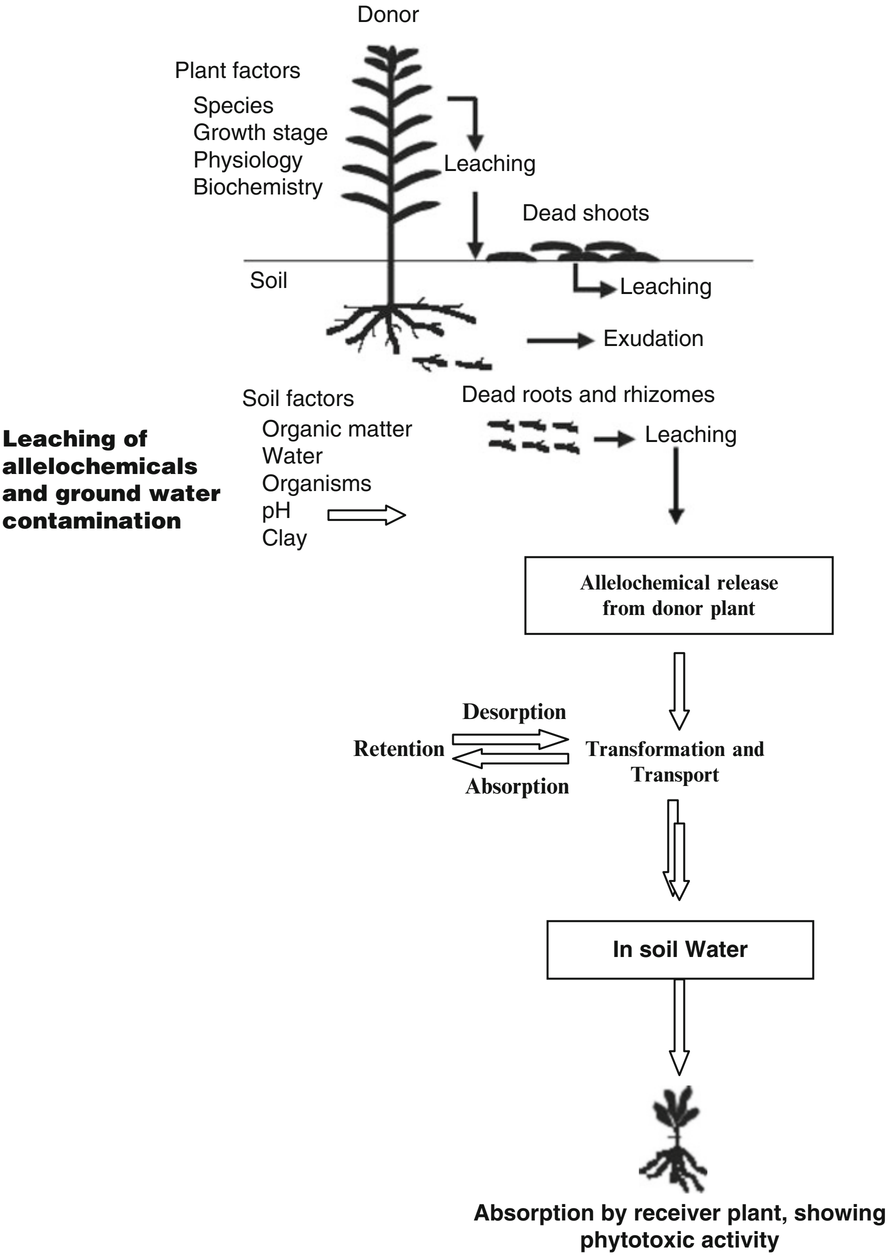

Fig. 2 Leaching of allelochemicals and its effects on receiver plant

Plant derived antimicrobial agents that include essential oils, alkaloids, phenols, flavanoids, tannins and sterols (Burt 2004; Halama and van Haluwin 2004) can contribute to disease control because of their enormous diversity. Many allelochemicals have been identified and characterized so far and includes Heliannuols and guaianolides from *H. annuus* (Macias et al. 1999); 14,15[beta]-Epoxy-prieurianin from bark of *Guarea guidona* (Lukacova et al. 1982); Valtrate from *Valeriana capense* (Fuzzati et al. 1996); insecticidal pyrethrin I and pyrethrin II from *Tanacetum cinerariifolium* (Staudinger and Ruzicka 1924); Nicotine from *Nicotiana tabacum* (Elliott et al. 1974), Azadirachtin from *Azadirachta indica* (Butterworth and Morgan 1968; Abbasi et al. 2005; Rani et al. 2006); rotenone from *Derris urucu* (Geoffrey 1985), glucosinolates like glucoraphenine isothiocyanate and allyl-isothiocyanate from mustard and horseradish (Ishiki et al. 1992; Delaquis and Mazza 1995) to name a few.

Even though performance of these allelochemicals is considered inferior to non-natural chemical pesticides, the environment friendly and low toxic nature of the allelochemicals outweighs the harmful effects of chemical pesticides, thereby making it one of the most promising and safe alternative to the chemical pesticides and fungicides.

5 Application of Biotechnology in Extraction and Purification of Allelochemicals

Biotechnological approaches employing tissue culture, DNA recombination technology, microbial fermentation, etc. have facilitated easy manipulation of sources and extraction of large quantities of pure allelochemical compounds. Plant tissue culture systems like cell culture and micro propagation etc., aid in the synthesis of large quantities of secondary metabolites without much interference from climatic factors (Junaid et al. 2010). The hairy root cultures, for example, are seen to be one of the most efficient systems for the production of secondary metabolites that are normally biosynthesized in roots (Hu and Du 2006). DNA recombination technology has also facilitated manipulating the metabolic pathways to enhance production of secondary metabolites (Capell and Christou 2004; Park et al. 2002). There have been many attempts to modulate biosynthetic pathway to enhance production of secondary metabolites (Park et al. 2002; Verpoorte and Memelink 2002).

Integration of molecular and genetic approaches may aid in the allelochemicals production in plants. Incidences of multi-gene engineering to introduce completely novel pathways and thus to produce completely new products have also been reported (Tattersall et al. 2001). Identification of individual genes and analysis of their expression pattern is a powerful tool to focus rapidly on genes that can improve complex traits. If operational genetic transformation systems are available for crops, transgenics have a great potential for the test and verification of gene functions identified by classical breeding and marker assisted selection. Areas in the genome of importance for trait variation, i.e., quantitative trait loci (QTL) for complex traits, such as water and nutrient use efficiency, have been identified in mapping populations of major agricultural crops and potential energy crops (Hirel et al. 2001; Rönnberg-Wästljung et al. 2005; Manneh et al. 2007).

Thus, the new tools of molecular biology and plant biotechnology provide much better opportunities to enhance the production and extract large quantities of high quality allelochemical for their use in pest and disease management.

6 Conclusion

Although application of weed and pest controlling chemical agents have steadily increased, yet a number of pesticides have well-documented negative consequences on the environment and on human health. Therefore biological control offers a number of alternative approaches for pest, disease and weed control in agriculture (Jordan 1993; Bond and Grundy 2001; Mason and Spaner 2006), but the application of biological weed control has often been proved difficult in practice (Müller-Schärer et al. 2000). Allelopathy is a promising component of biological control measures (Lovett 1991) which may have direct or indirect effect of one plant (or microorganism) on another mediated through the production of chemical compounds that escape into the environment (Rice 1974; Macías et al. 2007). A comprehensive understanding of the chemical complexities seen in different taxa can thus be utilized towards developing measures for crop protection. Encouraging results have been documented and reported regarding the crucial role played by these antimicrobial secondary metabolites in plant-pathogen interactions. Development of these non-chemical/synthetic plant based formulations on a commercial scale is gaining considerable momentum considering the merits that includes negligible risk to human health and environment as against the chemical pesticides. As many of these secondary metabolites have proven biological activities, scale-up production of active principles/preparations of secondary metabolites, from resistant plants can be optimized and exploited for development of environment friendly biopesticides/microbicides. Alternatively, strategies can be developed through metabolic engineering to mediate the synthesis of these defensive secondary metabolites in susceptible cultivars to combat the invading pathogens.

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Rice Bed Planting and Foliar Fertilization

M.H.M. Bhuyan, Most R. Ferdousi, and Md. Toufiq Iqbal

Abstract Rice grain yield must be increased with the pace of increasing population. Despite varietal improvement, it is greatly needed to increase the production through improved management. Bed planting in rice-rice cropping systems is a promising technique for improving resource use efficiency and increasing the yield. Bed planting has advantages such as resource conservation, resource use efficiency and profitability. Benefits can also be obtained by reduced tillage direct seeding, increased crop diversification, mechanical weeding, mechanical placement of fertilizers below the soil surface, reduced seed requirement, reduced cost of irrigation. Bed planting with foliar nitrogen fertilizer application of rice production systems very new.

Influence of foliar application of nitrogen fertilizer on transplanted aman rice, and evaluation of water and fertilizer application efficiency of rice-fallow-rice cropping system was investigated under raised bed cultivation. Result showed that foliar spray in bed planting increased grain yield of transplanted aman rice up to 9 %. Foliar nitrogen fertilizer application in bed planting increased the number of panicle, number of grains and 1,000-grain weight of rice. Sterility percentage and weed infestation were lower at foliar nitrogen fertilizer application in bed planting. 39 % irrigation water and time for application can be saved by foliar nitrogen spray in bed planting. Water use efficiency for grain and biomass production was higher by foliar nitrogen fertilizer application in bed planting. Likewise, agronomic efficiency of

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foliar nitrogen fertilizer application in bed planting method was higher. We conclude that foliar nitrogen spray in bed planting method is a new approach to get fertilizer and water use efficiency as well as higher yield compared to existing agronomic practice in Bangladesh.

Keywords Agronomic efficiency • Leaf area index • Sterility • Harvest index • Resource conservation and agricultural productivity

1 Introduction

Rice (*Oryza sativa* L.) belongs to cereal group of crops under Gramineae family. It is the staple food of a vast majority of people around the world. Rice occupies the first position among the crops covering about 75 % arable land in Bangladesh. In 2006–2007, 10.58 million hectares of land was under rice cultivation which produced 27.31 million tons of rice (BBS 2007). It provides about 75 % of the calories and 55 % of the protein in the average daily diet of the people of the country (Bhuyan et al. 2002). The climatic and edaphic conditions of Bangladesh are favorable for year round rice cultivation. Although Bangladesh ranks 4th in terms of both acreage and production in the world, the average yield of rice is low in Bangladesh, only 2.73 t ha^{-1} (BBS 2007).

Bangladesh is a densely populated country and at resent its population growth rate is 1.43 % (BBS 2007). Rice production is decreasing day by day due to high population pressure. The possibility of horizontal expansion of rice production area has come to stand still (Hamid 1991). As there is very little scope fro horizontal expansion of crop production in Bangladesh, farmers and agricultural scientists are diverting their attention towards vertical expansion for increased crop production. Therefore attempts should be taken to increase the yield per unit area by applying improved technology and proper management of fertilizers to achieve the goal.

Soil fertility depletion is a major constraint for achieving higher crop yield in Bangladesh. Of the nutrients deficient in Bangladesh soils, nitrogen deficiency is most remarkable. For this reason farmers are using urea fertilizer (46 % N) to a large scale. Nitrogen is one of the major plant nutrients required for plant growth. For maximizing yield of rice, nitrogenous fertilizer is the kingpin in rice farming.

Nitrogen can dramatically stimulate plant productivity, especially it encourages above ground vegetative growth of plants. A good supply of nitrogen also stimulates root growth and development. It is essential for the synthesis of protein, which is the constituent of protoplasm and chloroplasts. It is a constituent of numerous important compounds found in living cells, including amino acid, protein (enzymes), nucleic acid and chlorophyll (Traoce and Maranville 1999). This element is the most essential element in determining the yield

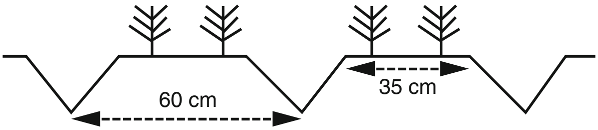

Fig. 1 Two rows of rice on the top of the beds (TPR)

potential of intensified agriculture system (Mae 1997). But nitrogen use efficiency is very low and the recovery of N in wetland rice seldom exceeds 40 % (De Datta and Buresh 1989).

1.1 The Furrow Irrigated Raised Bed Planting System

The height of the beds is maintained at about 15–20 cm and having a width of about 40–70 cm depending on the crops (Fig. 1). The furrow width is generally 25 cm. During the last decade practice of raised bed planting has been emerge with a greater pace in Indo-Gangetic Plain. The major concern of this system is to enhance the productivity and save the irrigation water. There are evidences for the greater adoption of this practice in the last decade in other parts of the world like high-yielding irrigated areas.

The use of raised beds for the production of irrigated non-rice crops was pioneered in the success of beds for wheat-maize systems in Mexico (Meisner et al. 1992; Sayre and Hobbs 2004). Potential agronomic advantages of beds include improved soil structure due to reduced compaction through controlled trafficking, and reduced water logging and timelier machinery operations due to better surface drainage. In the Indo-Gangetic Plain beds also create the opportunity for mechanical weed control and improved fertilizer placement. However, we hypothesize that many other potential benefits will lead to increased productivity and profitability (Connor et al. 2003) through permanent beds, including

- Reduced tillage and direct seeding with permanent beds that reduce costs of labour, diesel, and machinery when offset against the costs of initial bed formation and maintenance.
- Increased opportunities for crop diversification in both the wet and dry seasons that allow response the market opportunities as well as to the reduced supply of water.
- Mechanical weeding and inter-culture operations in wheat and other non-rice crops that reduce herbicide or labour costs-these advantages may also extend to rice on beds.
- Mechanical placement of fertilizer below the soil surface, leading to improved fertilizer use efficiency.
- Reduced seed requirement of a range of crops compared with flat surfaces.

- Reduced cost of irrigation-this includes the digging, maintenance, and deepening of wells as well as power pumping and labour time for irrigation.
- Greater yields of all crops that can be obtained in response to better soil structure and surface drainage, more timely sowing because of direct seeding and good drainage, and other management operation.
- Current and impending water scarcity-bed culture promotes the possibility (i) to grow rice with intermittent irrigation to save water and (ii) to diversify crops to other less water-demanding crops.

To meet the increasing food demand, rice production must be increased and continued. Bed planting rice production systems may be a technique for improving the yield. In this system, the land is prepared conventionally and raised bed as well as furrows are prepared manually or using a raised bed planting machine. Crops are planted on rows in top of the raised beds and irrigation water is applied in the furrows between the beds. Water moves horizontally from the furrows into the beds. This system is often considered for growing high value crops that are more sensitive to temporary water logging stress.

1.2 The Conventional Planting with Flood Irrigation System

In conventional method, for transplanting rice, land is prepared by puddling the soil. For direct seeding of pre-germinated rice seed, land is also prepared by puddling. Puddling and continuing inundation until maturity have significant effects on the physical, chemical and biological status of soils that influence the growing conditions for all acrops in the system (Sharma and de Datta 1986; Kleinhenz and Schnitzler 1996). Puddling softens soil, facilitates transplanting of rice, promotes root growth, aids weed control, and reduces water and nutrients losses through leaching. Though puddling offers significant advantages to rice but it may not be necessary in fine – textured soils (Utomo et al. 1996). It causes many problems for following non-rice crops such as destruction of soil structure leading to higher bulk density, higher soil penetration resistance and enhanced surface cracking.

In the next two decades, fresh water will be increasingly scared in South Asia and water table in some areas are already dropping as much as 1 m per year. Although in Bangladesh ground water level is recharged at the end of the monsoon season, the recharge pattern is in declining trend (Parveen et al. 2004). Heavy diesel use for irrigation and tillage, and crop residue burning pose local health hazards and add CO_2 significantly to global warming. So alternative tillage practices that reduce resource use and cost and raise productivity are to be developed and tested.

1.3 Different Application Methods of N-Fertilizer

Many factors determine the fertilizer efficiency for rice crop during cultivation such as soil, cultivar, season, environment, planting time, water management, weed control, cropping pattern, source, form, rate, time of application and method of application (De Datta 1978). Prilled urea (PU) is a fast releasing nitrogenous fertilizer which is usually broadcast in splits, that causes considerable losses as ammonia volatilization, denitrification, leaching, surface run-off etc. On the other hand, deep placement of slow release nitrogenous fertilizer such as urea super granule reduces the nitrogen loss as well as increases its efficiency in wetland rice. Like urea super granule, urea mega granule also provides a steady supply of available nitrogen through out the growing period of the crop. Urea mega granule appeared more effective as because of one urea mega granule replaces three urea super granule to be placed in the centre of four hills in boro paddy. Application of coated urea is another technique of urea application. In order to improve nitrogen use efficiency of crops, some coated urea like sulphur coated urea, polymer coated urea has been examined for inhibition of urea hydolysis (Rao and Ghai 1987; Tendon 1987; Vyes and Mistry 1985).

1.4 Foliar Spray of N-Fertilizer

Foliar spray of fertilizer did not only increase the crop yields but also reduce the quantities of fertilizer applied through soil. Foliar application can also reduce the lag time between application and uptake by the plant (Ahmed and Jabeen 2005). The use of foliar fertilizing in agriculture has been a popular practice within farmers since the 1950s, when it was learned that foliar fertilization was effective. Radioisotopes were used to show that foliar applied fertilizers passed through the leaf cuticle and into the cells (Brasher et al. 1953). Various studies has shown that a small amount of nutrients (nitrogen, potash or phosphate) applied by foliar spraying increases significantly the yield of crops (Rauthan and schnitzer 1981; Malik and Azam 1985; Chen and Aviad 1990; Tattini et al. 1990; David et al. 1994; Gamiz et al. 1998; Asenjo et al. 2000; Haq and Mallarino 2000).

In fact, foliar fertilization does not totally replace soil applied fertilizer but it does increase the uptake and hence the efficiency of the nutrients applied to the soil. This application technique is especially useful for micronutrients, but can also be used for major nutrients like N, P, and K basically because the amount applied at any time is small and thus it requires several applications to meet the needs of a crop. The increased efficiency reduces the need for soil applied fertilizer, reduces leaching and run off of nutrients, reducing the impact on the environment of fertilizer salts (Ludders and Simon 1980; Suwaranit and Sestapukdee 1989; Venugoplan et al. 1995).

Little information is available about the effects of foliar nitrogen fertilizer application on yield and growth response of transplanted aman rice under raised bed over conventional method. Foliar application of nitrogen fertilizer may be the most effective means for maximizing yield of rice. Our previous study showed that water use efficiency and grain production were higher in raised bed than conventional cultivation method (Bhuyan et al. 2012). However, it was not considered for foliar spray of nitrogen fertilizer in raised bed than conventional method. Therefore, this study was undertaken to determine the effect of foliar nitrogen fertilizer spray on raised bed over conventional cultivation method. It was hypothesized that foliar fertilizer spray on raised bed receives higher fertilizer use efficiency and yield than conventional cultivation method.

2 Review of Literature

2.1 Bed Planting in Rice

Hobbs and Gupta (2003a) reported that a farmer obtained 9 t ha^{-1} of rice transplanted on beds and saved more than 50 % of the water than normally applied on flat-surface transplanted rice. Flat-surface planted rice yielded from 7 to 8 t ha^{-1}, slightly less than beds because it lodged. They mentioned that the use of beds also provided a way for improving fertilizer use efficiency. This was achieved by placing a band of fertilizer in the bed at planting or top-dress.

Gupta and Zia (2003) mentioned that bed planting reduced irrigation water requirement by 25–50 % while the growth and yields of transplanted rice on bed could be comparable or more than traditional rice culture.

Balasubramanian et al. (2003) reported that bed planting was tried for rice for the first time in India, during 2000 wet season and in Nepal, during 2001 wet season. The preliminary results were highly encouraging. They reported good crop performances, high yields, and considerable savings in irrigation water in the raised bed system compared with transplanted flooded rice. They mentioned that, transplanting on bed was the best since the normal herbicides used for transplanted rice could be used to control weeds.

Hobbs and Sayre (2003) reported that planting crops on raised beds provided certain benefits not possible under flat bed planting. In rain fed systems that helped conserve moisture and in irrigated systems water application, distribution and efficiency was enhanced. the main benefits from the system included water savings (up to 35 %), provision of mechanical weed control, the ability to place fertilizer (basal and topdressing) for higher efficiency, lower seed rates and reduction of lodging losses.

Gupta et al. (2003a) observed that crop lodging was generally less in zero-till and raised bed planted corps. In zero-till system, plant seemed to receive good mechanical support from undisturbed soil in the close vicinity of the narrow slits. Also higher root biomass provided better anchorage to plants against lodging. They also observed that the crop lodging was more likely in puddled transplanted rice than the one planted on raised beds.

Connor et al. (2003) showed that the savings in irrigation water were 41.5 and 17.8 % by transplanted rice on beds and direct seeded rice on flats, respectively, over conventional tillage. The average water savings and yield increase by bed planting of different crops were 31.2 and 24.2 %, respectively. For individual crops, these were maize (35.5 and 37.4 %), mungbean (27.9 and 33.6 %), wheat (26.3 and 6.4 %) and rice (42.0 and 6.2 %). From a participatory trial in India Connor et al.

(2003) reported that higher panicle length of rice was found in transplanted rice on beds (23.4 cm) than direct seeded rice on flats (21.9 cm) and conventional tillage (21.5 cm). Number of grains panicle^{-1} was also higher in transplanted rice on beds (173) than direct seeded rice on flats (163) and conventional tillage (163).

Many scientists reported of irrigation water by bed planting compared to conventional methods. The savings ranged from 18 to 30–50 % (Hossain et al. 2001a; Talukder et al. 2002; Hobbs and Gupta 2003b; Humphreys et al. 2004).

Cabangon and Tuong (2005) stated that conventional rice culture gave slightly higher yields than rice on raised beds. Despite lower rice yields in beds compared with flats, higher water productivity in bed treatments offered an option in rice farming system in irrigated areas, where rice was grown in sequence with other upland crops. Beds reduced irrigation and total water input by as much as 200–500 mm (20 to 45 %). In Asia, lowland rice was grown on more than 30 % of the irrigated land and accounts for 50 % of irrigation water and these savings had a significant impact on the total amount of water saved when extrapolated to the whole rice ecosystem.

2.2 Advantages of Bed Planting

Fahong and Xuqing (2001) reported several advantages of bed planting. It saved 40 % irrigation water, improved soil properties and micro-climate in the field, which was beneficial to crop growth and development such as reducing the height of the plant, increasing the lodging resistance and disease resistance. These increased the yield potential of the crops by 10–20 %.

Connor et al. (2003) synthesized the advantages of bed planting over flat method which were (i) improved, simpler and more efficient irrigation management, (ii) On an average it used 30 % less water and improved crop yields by more than 20 %, (iii) better upland crop production because of better drainage, (iv) increased fertilizer efficiency, (v) better tillering, increased panicle length and bolder grain (vi) reduced lodging, (vii) mechanical weed control and (viii) yield potential could be enhanced through improved nutrient- water interactions and less lodging.

Kukal et al. (2005) described the potential agronomic advantages of raised beds that included improved soil structure due to reduced compaction through controlled trafficking, reduced water logging and timelier machinery operations due to better surface drainage. Permanent raised beds might offer water savings as compared to flat planting.

2.3 Zero-Tillage

The potential advantages of zero reduced tillage planting systems are early and timely planting of crops; increased nutrient, water and land use efficiency; 20–30 % water savings: reduced fuel use for land preparation; reduced erosion; reduced production costs; increased profits; improved crop turn-around times; immediate advantages of residual moisture from the previous crop; improved soil physical, chemical and biological characteristics; enhanced flora and fauna biodiversity and reduced incidence of many annual grass and broad leaf weed species (Gupta 2003; Gupta et al. 2003; Gupta and Gill 2003 and Hobbs 2003a).

Hobbs (2003b) reported the main problems faced by the farmers using zero-tillage were clogging of the drill by loose stubbles after combine harvesting rice, increased rodent activity in some fields, infestation by carryover weeds from rice to wheat and rice stem borer infestation. He suggested the solutions of the above-mentioned problems such as by developing a suitable drill that allows planting in to the loose crop residues, by taking required rodent control measures, by suing herbicides or better weed control in rice and control measures for stem borer to some extent.

Mehla (2003) calculated that adoption of zero-tillage on five million ha would represent a saving of five billion cubic meters of water each year. That would fill a lake 10 km long, 5 km wide and 100 m deep. In addition, annual diesel fuel saving would come to 0.5 billion liters, equivalent to a reduction of nearly 1.3 million tons in CO_2 emissions each year.

Kataki (2003) expressed that reduced and zero tillage improved timelines of sowing and through the same system interactions, helped farmers cope with crop production problems. These practices improved nutrient use efficiency and reduced weed germination.

2.4 *Effects of Foliar Application of Fertilizers*

Field experiments were conducted by Ravi et al. (2007) at Annamalai University Experimental Farm (Tamil Nadu, India) during Navarai and Kuruvai season to study the effect of foliar spray of phytohormones and nutrients on the yield and nutrient uptake of transplanted rice cultivar ADT 36. The results revealed that foliar application of miraculan at 1,000 ppm recorded an beneficial effect over other treatments.

Singaravel et al. (2007) conducted an experiment to study the effects of recommended NPK rates (120:38:38 kg ha^{-1}) with or without Kiecite, a foliar micronutrient mixture containing 1.0 % Fe, O.5 % Mn, 5.0 % Zn, 0.35 % Cu and 0.05 % B, at 0.50, 1.05, 1.5 or 2.0 % on the performance of rice (cultivar. ADT 43) were studied in Annamalai, Tamil Nadu, India, from July to October 2003. They reported that NPK and 1.0 % Kiecite significantly enhanced the growth and yield of rice.

An experiment was conducted by Seilsepour (2007) to study wheat grain protein increasing through foliar application of nitrogen after flowering. The randomized complete block design was analyzed with three replications and four N-treatments as foliar application as ($N_0=0$, $N_1=4$ kg ha^{-1} Urea $N_2=8$ kg ha^{-1} Urea, $N_3=4$ kg ha^{-1} Ammonium Sulfate). Results showed that seed protein content increased significantly by foliar application of nitrogen.

Moeini et al. (2006) conducted a 3-year trial from 1999 to 2001 in Karaj, Iran. Treatments included herbicide combination at nine levels and urea application in two methods (foliar application and top dressing). The results indicated that foliar application of urea had a significant effect on yield. Tank mixing urea with herbicide had no effect on herbicide use efficiency. Among combinations, urea and tribenuron-methyl and clodinafop-propargyl were the best for controlling weeds and increasing grain and biological wheat yield.

Krishnaveni and Balasubramanian (2003) conducted a field experiments at Madurai, Tamil Nadu, India, during 1997–1998 and 1998–1999, to investigate the influence of nutrient management, foliar application of growth regulators and plant product on productivity of rabi rice and reported that among the light management practices, foliar spray of triacontanol at 2 ppm given at 35 and 65 days after transplanting significantly recorded the highest grain yield of 6,328 kg ha^{-1}.

Satheesh et al. (2003) conducted an experiment during the 1999 rabi and 2000 kharif seasons in Hyderabad, Andhra Pradesh, India, to determine the effect of foliar applied NPK fertilizers on the growth and yield of rice cultivars Pro Agro 6201 (hybrid) and Ajaya (high yielding). The treatments comprised 100 and 75 % NPK fertilizers, alone or in combination with 2 % Polytfeed (19:19:19), 2 % Polyrice (15:15:30) and 2%multi-K (13:0:46). Pro Agro 6201 had the highest panicle per m^2, panicle weight, and 1,000-grain weight with NPK at 75 % and three sprays of Polyrice (at panicle initiation, 1 week before and after flowering) had the highest panicle per m^2, which was at par with 100 % NPK and three sprays of Polyrice during both seasons. Pro Agro 6201 had the highest mean grain yield (5.85 t ha^{-1}), straw yield (8.15 t ha^{-1}) and harvest index (41.61 %).

Vaiyapuri and Sriramachandrasekharan (2003) were studied to study the effect of foliar application of phytohormones triacontanol and salicylic acid and nutrients diammonium phosphate and ZnSO4 on lowland rice at various concentrations along with the recommended dose of NPK on the growth, yield and nutrient uptake revealed that triacontanol sprayed at 0.1 % registered the highest plant height (81 cm), number of tillers $hill^{-1}$ (8.02), grain yield (4.71 t ha^{-1}), straw yield (7.25 t ha^{-1}) and uptake of nutrients (106.7,29.0,51.8 kg NPK ha^{-1}) and significantly superior to $ZnSO_4$, diammonium phosphate, salicylic acid and water spray. Foliar spray of higher concentrations of either growth hormones or nutrients caused reduction in growth and rice yield.

Duraisami and Mani (2002) had conducted field experiments during the winter of 1994–1995 and 1996–1997 to determine the suitable nutrient management for rice. The treatments comprised soil application of 100 % recommended NPK rate (T_1), T_1 and 20 % additional N (T_2), 50 % recommended N and 100 % recommended P and K rates and 2.5 urea foliar spray at the active tillering, panicle initiation, mid-heading, first flowering and 50 % flowering stages (T_4), T1 and 2 kg phosphor bacterium ha^{-1} (T_5), T1 and 25 kg $ZnSO_4$ (T_6), T1 and 2 % urea foliar spray application at active tillering and panicle initiation stages (T_7), and T1 and 1 % $ZnSO_4$ spraying at active tillering and panicle initiation stages (T_8). T_2 resulted in the tallest plants (101.9 cm) and highest number of productive tillers (10), grain yield (6,713 kg ha^{-1}) and straw yield (9,183 kg ha^{-1}), whereas T_3, T_4 and T_7 gave the highest chaff per panicle (12.4), harvest index (43.64 %) and number of grains per panicle, respectively.

Hard red winter wheat (*Triticum aestivum*) studies were conducted at two locations in Oklahoma, USA during 1997–2000 to evaluate the effects of late- season foliar N applications on grain yield, total train N, straw yield, and total straw N (Woolfolk et al. 2002). Foliar applications of N were made at two different times (pre and post flowering) using urea ammonium nitrate at 0, 11, 22, 34, and 45 kg N ha^{-1}. A significant linear increase in total grain N was observed for post flowering applications using urea ammonium nitrate in five of six site-years. No consistent increases of decreases form foliar N applications were observed for grain yield, straw yield, or straw N.

Pot experiment were conducted by Andreevska et al. (2001) to determine the effect of nitrogen fertilizers on the dry matter yield and the total nitrogen content in the roots, stems, leaves and panicles of rice. The complex fertilizer was applied as a basic treatment, while the nitrogen fertilizer was applied as a double foliar split application at the start of the heading stage. The result reported that the method and time of nitrogen application showed a significant positive effect on the yield increase of raw and dry matter of the roots and aboveground organs, and on their total nitrogen content.

Borjian and Emam (2001) conducted a field experiment in Shiraz, Iran, during 1998–1999, the effect of rate and time of foliar urea application on protein content and quality in two cultivars of winter wheat, ‘Flalat’ and ‘Marvdasht’, was studied. A split-plot arrangement of treatments in a randomized complete block design was used with cultivars as the main plots and factorial levels of five urea foliar application rates (0, 8, 16, 24 and 32 kg N ha^{-1}) and three stages of application (booting, and early-milk), as subplots. The results showed that each 8 kg ha^{-1} increment in N applied as urea was associated with a 0.65 increase in grain protein in both cultivars. Both grain yield and protein percentage increased, resulting in higher protein yield.

In a study conducted during 1996–1998 in Kalyani, west Bengal, India, crude extract of compound having growth promoting activity, obtained from Lantana camara leaves, when used as foliar spray on rice cultivar IR-36 resulted in appreciable increase in growth of the plants (Sukul and Chaudhuri 2001). The flowering date was considerably advanced and accompanied with increase in the length of the panicle and grain yield.

A field experiment was conducted by Badole and Narkhede in (1999) Maharashtra, India during 1995–1998 to study the effect of foliar spray of 2 % urea for six times at 10 day intervals (27.5 kg N ha^{-1}) and three times at the tillering, panicle initiation and grain-filling stages, with and without basal applications of NPK on transplanted rice (Oryza sativa cv. Sye-75). The growth and yield of rice increased significantly with the application of 50, 50 and 50 kg ha^{-1} (N:P:K) as a basal rate and foliar spray of urea at the three growth stages. This same treatment also recorded the highest values for the yield attributing characters.

Aguilar and Grau (1995) had studied that the alluvian soil was given 0–210 lb N acre^{-1} as urea before sowing 3 Joponica and 2 Indica type rice cultivars. Foliar analysis at 46, 59 and 67 day after sowing showed that N content decrease during tillering. For each phonological stage and cultivar the critical N content was established at which 90 % of maximum grain yield was achieved. This should reduce excessive N application and harmful effects on the environment. Japonica type and Indicia type cultivar gave highest grain yields following applications of 120 lb and 120–150 lb N acre^{-1} respectively.

Stefan and Steran (1990) conducted an experiment during 1987–1989. They used 0–120 kg N ha^{-1} applied to soil and 0–90 kg N applied to leaves of rice at 4–5 leaves, 7–8 leaves or shoot elongation, grain yields ranged from 3.52 to 3.08 t ha^{-1} without N to 7.77 and 6.60 t with 60 kg N applied to soil. Sixty kg N as urea applied four to five and five–seven to eight leaf stages in cultivar polizesti 28 and cristal respectively nutrition co-efficient and rice yield and quality increased with increase in use of liquid N fertilizer.

2.5 *Effects of Soil Application of Fertilizers*

Singh et al. (2008) conducted field experiments in patna, Bihar, India, from 2001–2002 to 2003–2004, to study the effect of irrigation and nitrogen (N) fertilizers on yield, water use efficiency and nutrient balance in a rice-based cropping system. Application of optimum levels of irrigation and N fertilizer increased the rice equivalent yield by 8.40, 4.38 and 6.90 % over the sub-optimum level in the both cropping systems.

A field experiment was done to determine the effect of different levels of N on N uptake, yield components and dry matter yield of japonica (Hatsuboshi) and indica (IR-13) rice varieties (Prudente et al. 2008). The results showed an increasing trend in N uptake, rice yield, panicle number, tiller number and dry matter production, with increasing the amount of applied N fertilizer. There was a 30 kg ha^{-1} increase in the yield of brown rice and about 1.4 % increase in the total N uptake for every additional kilogram of applied N ha^{-1}. The increase in yield could be attributed to the increase in N uptake with increasing N application.

Barnwal et al. (2007) conducted an experiment to evaluate the effect of different levels of nitrogen and karanj cake in relation to occurrence of diseases and yield of rice. Applied with 80 kg nitrogen as urea and 20 kg oil cake per ha recorded higher mean grain and straw yields of 44.9 and 98.2 q ha^{-1}, respectively.

A field experiment was conducted by Ghosh (2007) during the 2002 and 2003 wet seasons in cuttack, Orissa, India, to study the effect of stand density high at 150 cm^2 hill-at 15 × 10 cm spacing; medium or normal 300 cm^2 hill-at 15 × 20 cm spacing; and low at 450 cm^2 hill-at 15 × 30 cm spacing and N fertilizer rates (0, 40, 60 and 80 kg ha^{-1}) on the yield and N utilization of rice cultivar Sarala. The result reported that N at 60 kg ha^{-1} combined with low density stand produced the highest grain yield (3.40 t ha^{-1}).

Jia et al. (2007) conducted field experiments in China to determine the effect of the application of different nitrogen (N) fertilizer ration on the vegetative and reproductive stages of rice. Results showed that the suitable N fertilizer ratio applied during the vegetative and reproductive stages in rice was 7:3 and this application decreased production of non-productive tillers, increased production of effective tillers, enhanced kernel set and 1,000-grain weight and increased yield.

Li et al. (2007) evaluated the effects of nitrogen levels on grain yield and quality of rice under field grown conditions with a typical indica hybrid Shanyou 63 and a japonica cultivar Wuyujing three as materials and six N levels, 0, 8, 16, 24, 32 and 40 g m^{-2}, as treatment factors. N at 160 and 240 kg ha^{-1} could be the optimum rate for Shanyou 63 and Wuyujing 3, respectively, in the production for the high yield and good quality of rice.

Malik and Kaleem (2007) conducted a field study in Allahabad, Uttar Pradesh, India to evaluate the effect of N rates (100, 150 and 200 kg ha^{-1}) and application date on the performance of hybrid rice. Nitrogen increased grain yield, straw yield, harvest index, text weight up to 200 kg ha^{-1}. Split application of N produced higher values of yield components in both cultivars PAC-832 and PAC-801; when N was applied as basal, maximum tillering and panicle initiation.

Majumdar et al. (2007) Conducted a field experiment during 2001–2003 to study the effects of N (0, 30 and 60 kg ha^{-1}), farmyard manure 0 and 5 t ha^{-1} and seed inoculation with diazotrophs (Azotobacter chroococcum and Azospirillum braslense) on the yield, nutrient uptake by upland rice and the residual buildup of various forms of N in an acidic Alfisol. The result revealed that a combined dose of 60 kg N ha^{-1}, 5 t farmyard manure and seed inoculation with Azotobacter was the most suitable treatment for upland paddy production (3.9 t ha^{-1}), with adequate nitrogen buildup in the Alfisol.

Oo et al. (2007) conducted a field experiment during the rainy season of 2003 at the research farm of the Indian' Agricultural Research Institute, New Delhi to study the effect of N and S levels on the productivity and nutrient uptake of aromatic rice. Treatments comprised four N levels (0, 50, 100 and 150 kg ha^{-1}). The growth and yield attributes, grain, straw and biological yields increased significantly with increasing N levels. The increase in grain yield due to application of 100 and 150 kg N ha^{-1}over the control was 1.99 and 1.95 t ha^{-1} (or 49.5 and 48.5 %), respectively. Various n levels had a significant effect on grain, straw and total N, P, K and S uptake. Based on the total N uptake (grain and straw) there was 49.9, 63.9 and 70.4 % increase in the N uptake over the control with 50, 100 and 150 kg N ha^{-1}, respectively.

Prasad et al. (2007) conducted a field experiment in Pusa, Bihar, India to evaluate the effect of water stress and N levels (0, 40, 80 and 120 kg ha^{-1}) on the yield, N uptake and nutrient balance in rice cultivar Rajshree. N at 120 kg ha^{-1} resulted in the highest straw and grain yield. N at 120 kg ha^{-1} also resulted in higher N uptake compared to lower N levels.

Poshtmasari et al. (2007) from the Rice Research Institute of Iran-Deputy of Mazandaran (Amol) reported that nitrogen fertilizer rates and split application had significant effect on dry matter remobilization in shoot, stem and leave except flag leaf. This amount was obtained at the 100 kg ha^{-1} nitrogen fertilizer and the first split application treatment. The highest rate of dry matter remobilization in leaves except flag leaf was obtained in 200 kg ha^{-1} nitrogen fertilizer level. Also, flag leaf had the highest dry matter remobilization, although it was not affected by nitrogen fertilizer rates and split application.

Rahman et al. (2007) conducted on experiment in Agricultural University, Mymensingh during T. Aman season of 2002 to study the effect of different level of nitrogen on growth and yield of transplant aman rice. The experiment included four treatments this. 0, 60, 80 and 100 kg N ha^{-1}. Nitrogen level significantly influenced growth and yield components. The highest number of effective tillers hill^{-1}, maximum grains panicls^{-1} and highest grain yield and the highest harvest index i.e., maximum yield were obtained with 80 kg N ha^{-1}.

A field experiment was conducted by Sharma et al. (2007) during the rainy season of 2002 and 2003 at Sabour study the effect of nitrogen and weed management in direct-seeded upland rice (*Oryza sativa* L). Grain and straw yields of rice and N, P and K uptake by rice crop and weeds increased significantly with successive increase in nitrogen up to 120 kg ha^{-1}.

Tari et al. (2007) carried out a field experiment in Iran to study the effects of transplanting date (2,12 and 22 May), planting space (16 × 30, 20 × 20 and 25 × 25) cm and N application rates (92, 115 and 135 kg ha^{-1}) on morphological characters of a promising rice line (IR687-2). The N levels had significant effect on panicle length, 1,000 grain weight and grain yield of rice. The 1,000 grain weight, harvest index and filled grain percentage had the highest correlation with grain yield.

Nitrogen (N) application before transplanting, where N fertilizers are applied in seedling-bed and carried to the paddy field with seedlings, is a novel method for improving nitrogen utilization efficiency (NUE) in rice. The effect of this method on mineral N distribution in the rhizosphere soil was investigated in a field experiment with a japonica variety, Ningjing 2, in seasons of 2004 and 2005 (Zheng et al. 2007). There were four levels of N applied 16 h before transplanting: 0 N, 207 kg ha^{-1}. The result indicated that N fertilizer before transplantation had positive effect of increasing mineral N content in the rhizosphere soil of rice, thus improving NUE and grain yield.

A field experiment was conducted by Gobi et al. (2006) during the late pishanam season of 2001–2002, in Killikulam, Tamil Nadu, India, to evaluate the effect of plant population (40 and 50 hills m^{-2}), establishment method (line planting and seedling broadcasting), and split application of N and K (three splits of N and two splits of K; four splits of N and three splits of N and four splits of K) on the ‘growth and yield of hybrid rice (CORH-2). The result revealed that maximum values of growth and yield attributes as well as net returns and benefit: cost ratio were obtained with seedling broadcasting with 40 hills m^{-2} under five splits of N and four splits of K.

Field experiments were conducted by Mehla et al. (2006) at the Rice Research Station, in Kaul, Haryana, India, during kharif 2000, and 2001 to study the effect of N (at 0, 90, 115, 150 and 180 kg ha^{-1}) and water management practices (continuous submergence, irrigation 1 day after disappearance of standing water and irrigation 3 days after disappearance of standing water) on the yield and nutrient uptake by rice cultivar HKR-120. The yield and nutrient uptake by rice increased with the increase in N levels during all the years.

Manzoor et al. (2006) conducted a study during kharif season of three successive years from 2001 to 2003 at Rice Research Institute, Kala Shah Kaku, Lahore, Pakistan. Nine nitrogen levels (0, 50, 75, 100, 125, 150, 200 and 225 kg ha^{-1}) were studied to see their effect on paddy yield. According to the results plant height, number of productive tillers per hill, panicle length, number of grains per panicle, 1,000- grain weight and paddy yield showed increasing trend from pu to 175 kg N ha^{-1}. The yield parameters including paddy yield, number of grains per panicle and 1,000-grain weight stated declining at 200 kg N per hectare level and above. The maximum paddy yield (5.34 t ha^{-1}) was obtained from 175 kg N application which also produced higher number of grains per panicle (142.27 cm), along with maximum 1,000 grain weight (24.96 g). The plant height (145.56 cm), productive tillers per hill (19.67) and panicle length (36.62 cm) were the maximum at 225 kg N level.

Masud (2006) reported that application of nitrogen exerted positive effect on all crop characteristics. The rice genotypes differ significantly in yield contributing characters and grain yield.

The effects of nitrogen levels (0, 30 and 60 kg ha^{-1}) on rice (cv. MW-10) intercropped with greengram (cv. B-105) under different spatial arrangements were studied during the wet seasons of 2000 and 2001, on sandy loam soil, in Nadia, West Bengal, India (Patra et al. 2006) Intercropping of greengram with rice grown without nitrogen was the most efficient intercropping system, producing the highest yield advantage. The advantages in intercroppings were through higher yield components, land equivalent ratio (1.62), area time equivalent ratio (1.28), monetary advantages (Rs 10,318 ha^{-1}), net return (Rs 19,981) and benefit–cost ratio (2.73). An economy of at least 30 kg N ha^{-1} in intercropping with greengram could be possible when component crop of rice was grown without or at 30 kg N ha^{-1}.

Singh et al. (2006) from a field experiment in Ludhiana, Punjab, India, during kharif 2003 reported that N application significantly increased plant height number of grains panicle^{-1}, 1,000 grain weight and LAI but it did not influence the number of effective tillers plant^{-1}, panicle length and branches panicle^{-1}. A progressive and significant increase in grain and straw yield was observed with each increment of nitrogen up to 40 kg ha^{-1}. Overall acceptability score with respect to aroma, colour, flavour, tenderness and cohesiveness was increased with early transplanting less plant population and application of different levels of nitrogen compared to the control.

A field experiment conducted by Thakar et al. (2006) in Ludhiana, Punjab, India during kharif 2003 to evaluate the effect of date of transplanting, plant population and nitrogen level on yield and quality of Basmati rice. The result showed that date of transplanting did not influence plant height, leaf area index (LAI), straw yield and other yield attributing characters and produced statistically similar grain yield for Basmati rice. Plant population of 25 and 33 hills m^{-2} produced taller plant, whereas population of 44 hills m^{-2} recorded significantly higher LAI. The number of effective tillers plant^{-1} decreased significantly with increase in population. Nitrogen application significantly increased plant height, number of grains panicle^{-1}, 1,000- grain weight and LAI but it did not influence the number of effective tillers plant^{-1}, panicle length and branches panicle^{-1}.

Field trails were conducted by Teman and maslivets (2006) in Russia during 2004–2005 to study the effect of application of 90, 120 and 150 kg N ha^{-1} used with P and K fertilizers on yield of rice cultivars Liman and Leader at constant and short-term flood irrigation regimes. The results of investigations showed that 150 kg N ha^{-1} gave a good yield increase, and improved grain quality, i.e. grain glossiness, and the content of N, P and protein.

3 Results and Discussion

3.1 Grain Yield and Yield Components

The yield increased by foliar spray in bed planting over conventional method was 9.33 %. A similar finding was also found in panicles, grains per panicle and 1,000 g grain wt. Foliar spray in bed planting had more than 22 panicle number m^{-2}, 25 grain number per panicle and 0.22 g in 1,000-grain wt than conventional method (Table 1).

3.2 Other Plant Attributes

Planting method affected plant height, panicle length, non-bearing tillers m^{-2}, sterility percentage, straw yield and harvest index of rice. Plant height, panicle length and harvest index were higher by foliar nitrogen fertilizer spray in bed planting than

Table 1 Grain yield and yield components with respect to foliar spray in bed and conventional method

	Yield and yield components			
Method of fertilizer application	Grain yield (t ha^{-1})	Number of panicles m^{-2}	Number of grains panicle^{-1}	1,000 grain wt (g)
Foliar spray of Fertilizer in raised bed	4.68	298a	165a	23.10
Fertilizer broadcasting in conventional planting	4.37	276b	140b	22.88
Least Significance difference (LSD) at 5 %	0.26	3.34	4.98	1.32
Level of significance	n.s.	**	**	n.s.

Where ** represent probability of ≤0.01 and n.s. represents probability of >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$)

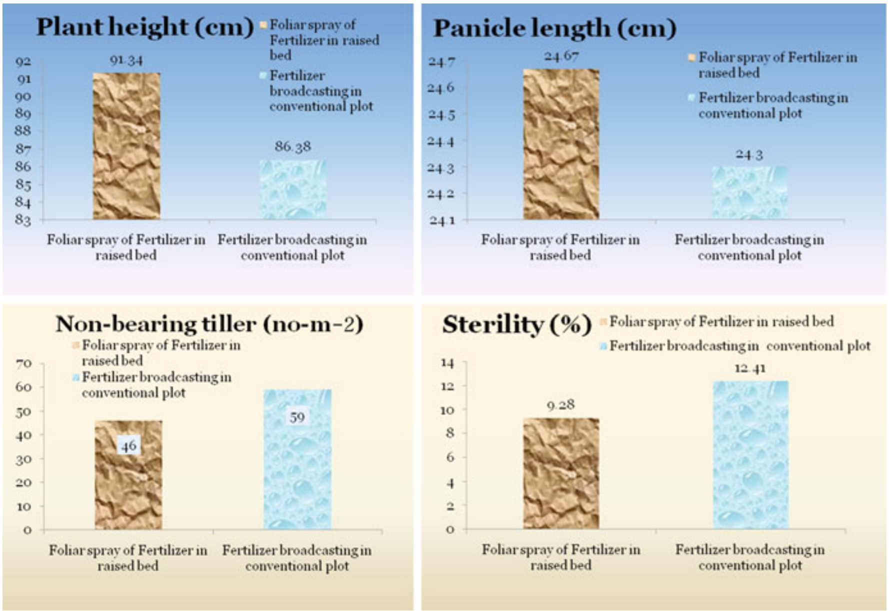

Fig. 2 Other plant attributes

conventional method. On the contrary, non-bearing tillers m^{-2}, straw yield and sterility percentage were higher in conventional method than foliar spray in bed planting. Likewise, lower number of non bearing tillers m^{-2} was recorded by foliar spray in bed planting treatments than conventional method. Foliar spray in bed planting significantly reduced the sterility percentage compared to conventional method. In bed planting sterility was lower. The lower sterility might be accountable for higher grains in bed planting. Bed planting resulted in higher harvest index than conventional method (Fig. 2).

3.3 *Tiller Production*

Transplanting of aman rice under different planting method affected the number of tillers m^{-2} of rice. The increasing trend of tiller m^{-2} was continued to 50 days after transplanting. At 50 days after transplanting both foliar spray in bed planting method attained the highest number of tiller m^{-2} and then started declining up to 100 days after transplanting. However, both method differ significantly ($P \leq 0.01$) from 20 to 100 days after transplanting (Fig. 3).

The number of panicles m^{-2} was significantly ($P \leq 0.01$) higher in bed planting over conventional method. The difference of panicles number was 22 m^{-2} between these methods (Table 1). Bed planting method produced significantly ($P \leq 0.01$) higher grains panicle than conventional method. Likewise, Borrell et al. (1998) found that panicles number m^{-2} in rice plant for raised bed planting and flooded

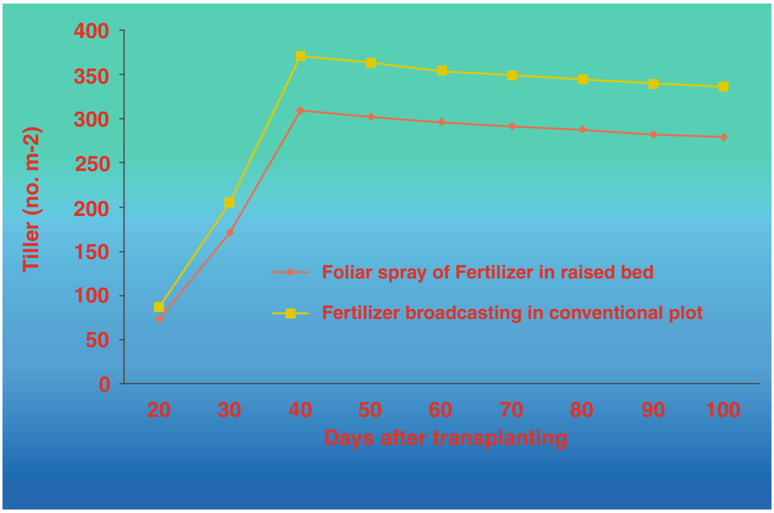

Fig. 3 Tiller production

method was 228 and 210 respectively. They also found that panicle number per plant in raised bed and flooded methods were 2.3 and 2.0 respectively. They speculated that the raised bed method has the potential to better utilize water and nutrients than conventional methods. This may result in higher panicle number per plant by foliar spray in raised bed than conventional method.

Planting method showed significant ($P \leq 0.01$) effect on plant height of transplant aman rice. Foliar spray in bed planting attends significantly higher plant height than conventional method. The lower plant height in conventional method indicated that the poor growth of plant that might influence the grain yield and yield components. Likewise, planting method significantly influenced the number of nonbearing tillers of transplanted aman rice. Foliar spray in Bed planting treatments irrespective of bed widths and plant rows per bed significantly ($P \leq 0.01$) reduced nonbearing tillers as compared to the conventional method. Similarly, planting method also affected sterility percentage of transplant aman rice. From the data presented in Fig. 2, it was revealed that foliar spray in bed planting system greatly reduced the sterility of transplanted aman rice compare to the conventional method. The low sterility in bed planting system might be the basis of higher grains panicle^{-1}, which directly added the grain yield.

The higher harvest index was obtained by foliar spray in bed and lower harvest index was obtained by conventional method (data not shown). The higher and lower harvest index was resulted due to higher and lower grain yield.

Foliar spray in bed planting method had 0.31 t ha^{-1} higher rice production over conventional method (Table 1). The yield increased by bed planting in transplant aman rice compared to conventional method was also reported by Hobbs and Gupta (2003a), Balasubranmanian et al. (2003), Meisner et al. (2005) and Jat and Sharma (2005). Likewise, Tang et al. (2005) also reported that bed planting method significantly increased rice yield by 6.7 % compared with traditional cropping technique.

Moreover, Ockerby and Fukai (2001) confirmed that yield of rice grown on raised beds were greater than rice grown in conventional method. They advised that effective N fertilizer utilized by rice paddy plants influenced better rice production in raised bed system. Other study speculated that potential agronomic advances of beds include improved soil structure due to reduced compaction through controlled trafficking and reduced water logging condition is responsible for improved rice production (Humphreys et al. 2005).

Weight of 1,000-grain was also higher in foliar spray in bed planting than conventional method (Table 1). Yadav et al. (2002), Zhongming and Fahong (2005) and Meisner et al. (2005) reported similar results. Likewise, Choudhury et al. (2007) found that 1,000 grain per g in flat bed and raised bed was 20.0 and 20.5 respectively. They speculated that higher grain production in raised bed than flat method could be due to management and geometry of bed, less weed population and better crop establishment.

3.4 Leaf Area Index

Planting method affected the leaf area index of transplant aman rice recorded at different days after transplanting . Plant-to-Plant distance in rows also influenced the leaf area index measured at different stages of crop growth. The highest leaf area index was achieved at 60 days after transplanting by foliar spray in bed planting method. After 60 days after transplanting the leaf area index was started declined and continued to 100 days after transplanting by foliar spray. It was also revealed that at early stage of crop growth the leaf area index by foliar spray in bed planting treatments was lower than conventional method. The highest leaf area index was achieved in conventional method was 80 days after transplanting. After 80 days after transplanting the leaf area index was started declined and continued to 100 days after transplanting by conventional method. However, leaf area index differ significantly ($P \leq 0.01$) between two methods from 20 to 40 days after transplanting (Fig. 4).

3.5 Dry Matter Production

Planting method affected the dry matter production of transplanted aman rice recoded at different days after transplanting. In the first date of measurement (20 days after transplanting) it was observed that the conventional method produced higher dry matter yield than foliar nitrogen spray in bed planting. Likewise, at the final date (100 days after transplanting) highest dry matter production was also recorded in conventional method than foliar spray in bed planting method. However, dry matter production differs significantly ($P \leq 0.01$) at different days after transplanting in both planting method (Table 2).

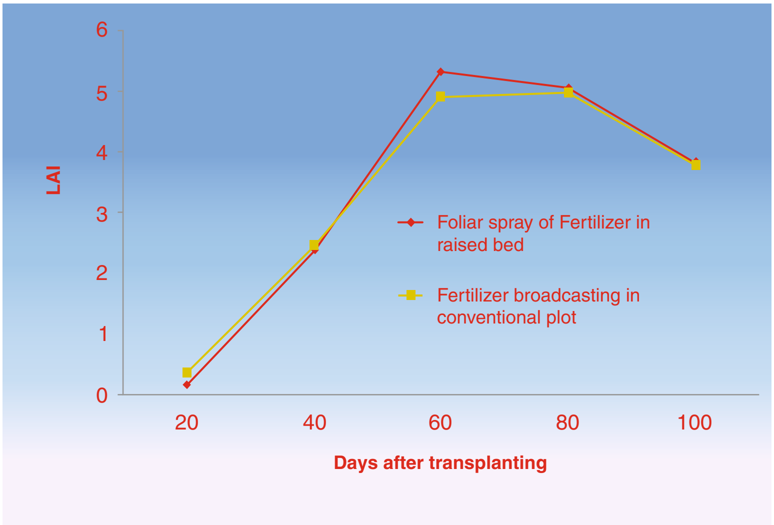

Fig. 4 Leaf area index

Table 2 Effect of dry matter production by foliar spray in raised bed and conventional method

Method of fertilizer application	Dry matter production (g m^{-2}) at different days after transplanting (DAT)								
	20	30	40	50	60	70	80	90	100
Foliar spray of Fertilizer in raised bed	36b	90b	242b	383a	576b	802b	913b	1094b	1198b
Fertilizer broadcasting in conventional planting	64a	127a	251a	350b	621a	851a	1062a	1190a	1260a
Least Significance difference (LSD) at 5 %	2.07	2.07	2.07	4.98	19.63	2.07	15.18	5.93	4.98
Level of significance	**	**	**	**	*	**	**	**	**

Where * and ** represents probability of ≤ 0.001 and ≤ 0.01, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$)

3.6 Crop Growth Rate

At the initial stage (20–40 days after transplanting), the crop growth rate by foliar spray in bed planting is lower than conventional method. The greatest crop growth rate was observed in 60–70 days after transplanting by foliar spray in bed planting method. On the other hand the highest crop growth rate was observed in 50–60 days after transplanting by conventional flat plot. The lowest crop growth rate was observed at 20–30 days after transplanting by both planting method. However, crop growth rate significantly ($P \leq 0.01$) differed between both planting methods at all days after transplanting except 60–70 days after transplanting (Table 3).

Table 3 Effect of crop growth rate by foliar spray in raised bed and conventional method

Method of fertilizer application	Crop growth rate (g m^{-2} day^{-1}) at different days after transplanting (DAT)							
	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100
Foliar spray of Fertilizer in raised bed	5.4b	15.2a	14.1a	19.3b	22.6	11.1b	18.1a	10.4a
Fertilizer broadcasting in conventional planting	6.3a	12.4b	9.9b	27.1a	23	21.1a	12.8b	7b
Least Significance difference (LSD) at 5 %	0.46	0.41	0.13	0.29	1.87	0.13	1.03	1.00
Level of significance	*	**	**	**	n.s.	**	**	**

Where *, ** and n.s. represents probability of ≤ 0.001, ≤ 0.01 and >0.05, respectively. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$)

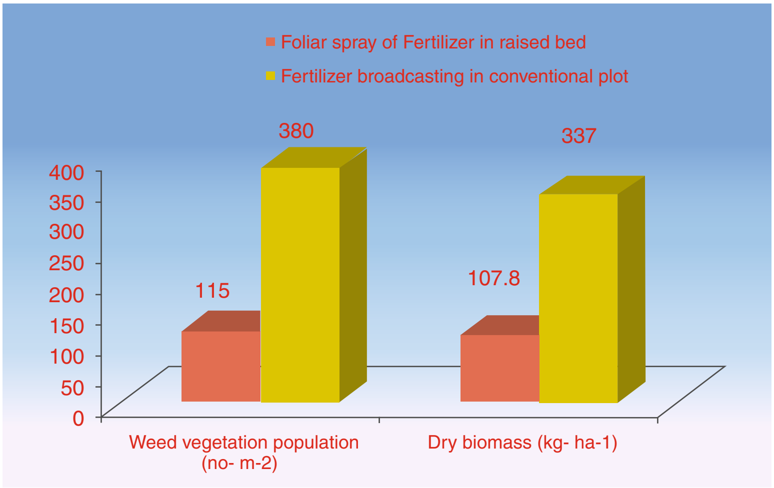

Fig. 5 Weed production

3.7 *Weed Population*

Weed population and dry biomass were greatly influenced by different planting methods of transplanted aman rice. The Foliar spray in bed planting method reduced weed population resulting in lower dry biomass than conventional planting. The conventional method had significantly ($P \leq 0.01$) higher weed vegetation than raised bed method (Fig. 5).

Weed production was significantly ($P \leq 0.01$) lower foliar spray in bed planting than conventional method. Likewise, existing weed vegetation was significantly ($P \leq 0.01$) lower in raised bed planting than conventional method (Fig. 5). Singh et al. (2008) found that total weed dry weight and weed density were lower in raised bed planting method as compared to conventionally puddle transplanted rice. Similarly, Ram et al. (2005) also found lower weed biomass in raised beds than the conventional method. They speculated that the low number of weeds in beds might be due to dry top surface of beds that inhibited the weed growth. However, our speculation is that, at the time of bed preparation, the top soils of the furrows were mulched to the raised beds, which drastically reduced the weeds in furrow. Another probable cause was that the soil was not disturbed in the zero tillage systems under bed planting method. Another speculation is that this difference of weed growth between bed planting and conventional method may be due to agronomic management practices. In bed planting method, rice plants were grown in wet conditions while in conventional methods, rice plants were grown under standing water condition. This difference in weed growth between these two methods could also have been due to the contrasting weed flora and soil moisture conditions of fields. Likewise, Hobbs (2001) opined that bed planting method reduces weed growth compared with conventional flat-bed planting method. He also suggested that bed planting provides additional options to farmers for controlling weeds. Similarly, Jat et al. (2005) suggested that planting of crops on raised bed systems reduces weed competition over conventional method. By adopting raised bed system, fertilizers are banded close to the rows enhancing crop accessibility to nutrient and competitiveness over weeds. The higher fertilizer use efficiency through better placement of fertilizer and faster drying of the top portion of raised bed is responsible for reduced infestation.

3.8 Irrigation Water

Amount of water required for different irrigations differed remarkably between the conventional and bed planting methods. The conventional method received the higher amount of water at every irrigation and total amount was 142.66 cm. The total amount of irrigation water received by foliar spray in bed planting was 102.47 cm. Result showed that total water savings by foliar spray in bed over conventional method was 39 % (Table 4).

3.9 Input Water Use

The differences in total water use between these two methods were 39 % higher in conventional over foliar spray in bed planting method for the entire cropping period (Table 4). Similarly, Thompson et al. (2003) grew rice on both raised beds and flat layout in small plots. They found that irrigation water savings of about 14 % using beds compared with flat layout. Studies in the USA have also shown considerable water saving with furrow irrigated rice on raised bed over conventional flooding method (Vories et al. 2002). Likewise, Beecher et al. (2006) found that water use in

Table 4 Irrigation water savings by Foliar spray in bed planting of rice production over conventional method

Method of fertilizer application	Water required at different times of irrigation (cm)					Water saved over conventional method (%)
	Land preparation	Transplanting	Reproductive stage	Rainfall	Total	
Foliar spray of Fertilizer in raised bed	–	6.35	43.62	52.50	102.47b	39
Fertilizer broadcasting in conventional planting	13.06	6.20	70.90	52.50	142.66a	
Least Significance difference (LSD) at 5 %	–	0.37	0.00	1.03	2.62	
Level of significance	n.s.	n.s.	n.s.	n.s.	**	

Where ** and n.s. represent probability of ≤0.01 and >0.05. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$)

flat and raised bed methods were 18.7 and 15.1 ML ha^{-1} respectively. They recommended that there is a good scope for saving water while maintaining yield on suitable rice soil through the use of raised beds. In another study, Boulala et al. (2012) speculated that compared to conventional method, the introduction of the raised bed planting system resulted in higher soil resistance to the penetration in the upper soil profile. This may protect deep percolation of irrigation water in the field. Regardless of that Wang et al. (2004) suggested that the better performance of raised bed over conventional methods was considered to be due to reduced water logging, improved soil physical properties, reduced lodging and decreased incidence of disease. However, our speculation is that the advantages come from the fact that irrigation water advances faster on bed planting soil than in a tilled soil and less water percolation loss in bed planting method over conventional method.

3.10 Water Use Efficiency

Water use efficiency for grain and biomass production by foliar spray in bed planting was 45.67 and 91.75 kg ha^{-1} cm^{-1} respectively. In contrast, water use efficiency for grain production and biomass production in conventional planting was 30.63 and 65.11 kg ha^{-1} cm^{-1} respectively. However, water use efficiency for grain production and biomass production by foliar spray bed planting over conventional was 49 and 40.88 % respectively (Table 5).

Table 5 Water use efficiency by foliar spray in raised bed and conventional method

Method of fertilizer application	Water use efficiency savings by foliar spray in bed planting of rice over conventional method Water use efficiency for grain production (kg/ha-cm)	Water use efficiency savings by foliar spray in bed planting of rice over conventional method Water use efficiency for biomass production (kg/ha-cm)
Foliar spray of Fertilizer in raised bed	45.67a	91.73a
Fertilizer broadcasting in conventional planting	30.63b	65.11b
Least Significance difference (LSD) at 5 %	1.85	5.04
Level of significance	**	**

Where ** represent probability of ≤ 0.01. Values were means of three replicates. In a column figures with same letter do not differ significantly whereas figures with dissimilar letter differ significantly ($P \leq 0.01$)

Fig. 6 Agronomic efficiency of fertilizer

3.11 Agronomic Efficiency of Fertilizer

Agronomic efficiency of fertilizer by foliar spray in raised bed was 93.82 %. On the other hand Agronomic efficiency for conventional planting was 43.67 %. Agronomic efficiency of fertilizer by foliar spray in raised bed was significantly ($P \leq 0.01$) higher than the conventional planting method (Fig. 6).

4 Conclusions

This study concludes that foliar spray in raised bed increased rice yield by 9.33 % when compared with conventional tillage on the flat. Raised bed also reduced irrigation water requirement by 39 % as well as increased irrigation efficiency. This finding concludes that water use efficiency for grain and biomass production were higher in foliar spray in bed planting than by the conventional method. The agronomic efficiency of fertilizer was also significantly higher in foliar spray of bed planting than the conventional method. The potential gains from growing rice production on raised beds are considered to be associated with better agronomic management than conventional method. Also, the crust problem on the soil surface was eliminated and soil physical status was greatly improved in bed planting plot over conventional flat system.

Based on the findings of this single season experiment, high yielding aman rice (depends on both irrigation and rainfall) crops have been successfully grown on raised bed under foliar spray; however, this research needs further validation. In this perspective, further study is under way to investigate yield and growth response of transplanted boro rice (completely depends on irrigation) under conventional and foliar spray on bed planting method.

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Integrated Nutrient Management and Postharvest of Crops

Hassan R. El-Ramady

> ***What*** *is common to the greatest number gets the least amounts of care.*
> ***Men*** *pay most attention to what is their own:*
> ***They*** *care less of what is common.*
>
> **–Aristotle**

Abstract Rational pursuit of sustainability is only possible if society could agree upon what sustainability is, or more exactly, if mankind knows what we want to sustain. Policy reforms are a requirement for achieving sustainability. Much can be achieved by promoting polices that help better resource allocation and at the same preserve the natural ecosystem. In addition, conservation incentives are needed through functioning of the marketplace, along with an assessment of alternative mechanisms to control externalities. Soils represent dynamic ecosystems, making it appropriate to think about them in terms such as health, vitality and biological productivity. Soils are the resources that provide humans with more than 90 % of all the food we eat. Our challenge is to manage soils in a sustainable fashion so that they will provide for human needs in the future. However, the measurement of soil processes and of the soil properties linked to these also depend on the use and location of the soil. When evaluating soil quality, it is therefore common to explore a range of soil physical, chemical, and biological properties.

Integrated Nutrient Management (INM) holds out great promise for meeting the growing nutrient demands of intensive agriculture and maintaining crop productivity at higher levels with an overall improvement in the quality of the resource base. INM involves proper combination of chemical fertilizers, organic manure, crop residues,

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nitrogen fixing crops, pulses and oil seeds and bio-fertilizers suitable to agroecosystem. The objectives of INM are to ensure the efficient and judicious use of all the major sources of plant nutrients in an integrated manner, so as to obtain maximum economic yield without diminishing soil fertility in order to sustain agricultural productivity and farm profitability.

Nanofertilizers have high use efficiency and can be delivered in a timely manner to a rhizospheric target. There are slow-release and supersorbent nitrogenous and phosphatic fertilizers. Some new generation fertilizers have applications to crop production on long-duration human missions to space exploration. On the other hand, biotechnology has numerous applications in soil science, especially in regard to microbiological assessment of soil quality, phytoremediation and detoxification of polluted soils, and in environmental safety. There are oil-oxidizing microorganisms that can restore soils contaminated by oil spills. Enhancing biological nitrogen fixation in cereals is another important application of biotechnology in soils. Judicious application of biotechnology can facilitate developments of plant genotypes that are tolerant to numerous biotic and abiotic stresses. Recombinant biotechnology and genetically modified organisms (GMO) plants have robust applications in the alleviation of biotic and abiotic stresses in soil systems. Environmental biotechnology is an important and a growing topic in soil science.

This review focusses on the integrated nutrient management to enhance plant nutrition, restore degraded soils, identify site-specific parameters as indicators of soil quality, and describe the impact of soil quality improvements on increasing agronomic production and advancing global food security. The relationship between integrated plant nutrition and postharvest of crops will be also addressed.

Keywords Integrated nutrient management • Sustainable agriculture • Postharvest management • Foliar nutrition

1 Introduction

It is well known that conservation, restoration, and enhancement of soil and water resources is essential to ensure humanity’s freedom from hunger and malnutrition, mitigate climate change, improve quality and quantity of fresh water resources, enhance biodiversity, generate ligno-cellulosic feed stock for biofuel production and improve income and living standards of rural population dependent on agriculture. In addition to traditional functions, soil resources must be managed to offset emissions of greenhouse gases, produce ligno-cellulosic feed stock and oil seeds for biofuels, improve quality and quantity of water resources, dispose industrial/nuclear and urban wastes, enhance biodiversity, improve ecosystem services, etc. Study of soil processes under urban land uses such as civil structures, lawns, recreational grounds, urban forestry and plastic house production of flowers and vegetables is important. There is a strong need to raise the profile of soil science professions, to revise and globalize soil science curricula, and develop close relations with allied sciences including geology, biology, climatology, ecology, hydrology, engineering, nanotechnology, biotechnology, information technology, and those dealing with the human dimensions. Soil scientists must develop channels of communication with these disciplines, land managers, industry entrepreneurs and policymakers, and also publish their findings in some mainstream journals e.g., Science, BioScience, Nature. There is a strong need for advocacy with policymakers, land managers, and public at large to provide support to the soil science programs at the Land Grant Universities and research/development institutions (Lal 2007a).

Food supply and agriculture production are integral parts of various aspects of development of humans. From a historical point of view the link has been very strong since with few exceptions, societies have relied almost completely on their agricultural production for survival. This has obviously had a tremendous effect on human, economic, social, cultural and technological development. But this link has never been a one-way influence. The availability of a secure food supply has affected countries and societies to reach particular social, economic or technological achievements. For example the great cultural achievements of ancient Egypt have only been possible with a secure food supply and a strictly organized agricultural production. Other similar examples from history include the ancient Greek and Roman Empires. On the other hand, empires collapsed following problems with food supply, which is evident for Babylon after the long term non sustainable irrigation and the salinization of the top soils. In the modern world with global trade of agricultural commodities such relations seem to have smaller importance, however, in a lot of countries in Africa, Asia and South America the link between agriculture and development is still very strong (Christen 2007).

It is worth to mention that, soil science must play a crucial role in meeting present and emerging societal needs of the twenty-first century and beyond for a population expected to stabilize around ten billion and having increased aspirations for a healthy diet and a rise in the standards of living. In addition to advancing food security by eliminating hunger and malnutrition, soil resources must be managed regarding numerous other global needs through interdisciplinary collaborations. Some of which are to mitigate global warming; to improve quantity and quality of freshwater resources; to enhance biodiversity; to minimize desertification; serve as a repository of waste; an archive of human and planetary history; meet growing energy demands; develop strategies of sustainable management of urban ecosystems; alleviate poverty of agricultural communities as an engine of economic development; and fulfill aspirations of rapidly urbanizing and industrializing societies. In addition to food and ecosystem services, bio-industries e.g., plastics, solvents, paints, adhesives, pharmaceuticals and chemicals through plant-based compounds and energy plantations such as bioethanol and biodiesel can revolutionize agriculture. These diverse and complex demands on soil resources necessitate a shift in strategic thinking and conceptualizing sustainable management of soil resources in agroecosystems to provide all ecosystem services while also meeting the needs for food, feed, fiber, and fuel by developing multifunctional production systems. There is a strong need to broaden the scope of soil science to effectively address ever changing societal needs. To do this, soil scientists must rally with allied sciences including hydrology, climatology, geology, ecology, biology, physical sciences, and engineering. Use of nanotechnology, biotechnology, and information technology can play an important role in addressing emerging global issues. Pursuit of sustainability, being a moral/ethical and political challenge, must be addressed in cooperation with economists and political scientists. Soil scientists must work in cooperation with industrial ecologists and urban planners toward sustainable development and management of soils in urban and industrial ecosystems. Soil scientists must nurture symbiotic/synergistic relations with numerous stake holders including land managers, energy companies and carbon traders, urban planners, waste disposal organizations, and conservators of natural resources (Lal 2007a).

It is widely agreed that the breathing spell provided by the green revolution for achieving a balance between population growth and food production will soon get exhausted, unless we take steps to foster an ever-green revolution based on principles of ecology, gender and social equity, economics, employment generation and energy conservation. Will the twenty-first century be one of hope or despair on the food front? Will there be enough water for human, agricultural, industrial and ecosystem needs? I would like to deal with these critical questions in the following four parts:

- Food security;
- Water security;
- Climate management;
- Safeguarding the ecological foundations of sustainable agriculture (agrobiodiversity).

The present global trends in the areas of preventing adverse changes in climate and sea level and in the protection of the ecological foundations for sustainable agriculture are not encouraging. However, there is still a chance for achieving the goals of "*food and drinking water for all*" in the coming century, because of the uncommon opportunities opened up by science and technology. The term "*green revolution*" was coined in 1968 by Dr William Gaud of the U.S. Agency for International Development to highlight the opportunities opened up by the semi-dwarf varieties of wheat and rice to increase production through higher productivity (Swaminathan 2004).

Humanity is at the crossroads as far as the global issues of food insecurity, climate disruption, and soil and environmental degradation are concerned. The strategy is to learn and change – alter land use and soil management to restore degraded soils and desertified ecosystems to a desirable stability/quality domain. The two key questions are:

1. How can we implement ways to expand human opportunity and facilitate human learning to sustain soil/ecosystem resilience?
2. How can we develop and implement soil/ecosystem/social resilience, integrated understanding, policies, and action among scientists, economic and public interest groups, and farmers and land managers so that knowledge and science-based action plan is evolved and implemented?

The strategy is of moving toward sustainable soil quality and agricultural improvement through research-based policies. Sustainable soil quality management approaches are those which permanently retain the ability of soils to provide ecosystem services and recover after an anthropogenic perturbation. These approaches involve weighing up of options, keeping options open, and creating new opportunities when old options are no longer feasible or become redundant (Lal and Stewart 2010b).

Therefore, this review will be focused on the integrated nutrient management to enhance plant nutrition, restore degraded soils, identify site-specific parameters as indicators of soil quality, and describe the impact of soil quality improvements on increasing agronomic production and advancing global food security. This will be based on the philosophy that "*Poor soils make people poorer*, *poor people make soils worse*, and *desperate humanity does not care about sustainability and stewardship*." So, it could be identified world-class soil scientists to contribute articles on issues of global significance.

2 Sustainable Agriculture

Partly as a result of lack of unanimity in the scientific circles, there is no single accepted definition of sustainable agriculture. The term "sustain" is derived from the Latin "*sustenire*", which literally means "*to uphold from falling*". If one takes this meaning of the word, it would suggest that sustainable agriculture is a static concept. However, this will be adequate only if demand for agricultural products was not changing, which could result under no population change, although even here, changes in tastes and preferences may alter demand level for various products. Obviously this concept of sustainability will become unacceptable if there is a rapidly growing population (as currently is the case). This will necessitate other improvements in this definition. Some authors have suggested that sustainability is a goal and not a set of well-defined practices. This philosophical anomaly perhaps stands in the path of developing a precise definition of sustainable agriculture. This may also explain, perhaps partly, the many interpretations of sustainable agriculture in the literature. One of the general definitions of sustainable agriculture is that it is ecologically sound, economically viable, and socially acceptable. This leads to a notion that sustainable agriculture should be one that seeks to achieve several objectives: efficient but complex diversified systems; conservation of ecology and natural resources including ground and surface water, and flora and fauna; conservation of non-renewable resources; and adequate and dependable farm incomes and healthy rural communities and institutions (Table 1; Kulshreshtha 2004).

In recent years the importance of sustainable agriculture has risen to become one of the most important issues in agriculture. The sustainability of agriculture has faced some of the most significant challenges in recent years. Major challenges include: (1) first of all, the rapid growth of the human population and the increased demand for agricultural land and resources, (2) overdependence on fossil energy and the increased

Table 1 Nomenclature used in the context of sustainable agriculture

Nomenclature	Description
Alternative agriculture	Describes production systems in agriculture that are different from the conventional agriculture. Farmers have a number of alternatives and have the freedom to choose among them. Less dependence on agro-chemicals is very common
Low-input sustainable agriculture	Agriculture requiring low dose of external inputs, thereby reducing production costs. Recycling of manure and crop residues is an important part of this system
Ecological/ecobiological/socioecological agriculture	Agriculture based on principles and processes that govern the natural environment. Protection of environment through reduced use of chemical fertilizer, herbicides and pesticides is an important aspect of such an agriculture
Regenerative/permaculture agriculture	Agriculture that has the continuing ability to recreate resources that the system requires
Biodynamic agriculture	Systems that use compost and humus to benefit soil structure and fertility
Organic agriculture	Based on recycling of nutrients from on-farm resources. Suggested to be a precursor of sustainable agriculture

Adapted from Kulshreshtha (2004)

monetary and environmental costs of nonrenewable resources, (3) global climate change, and (4) globalization (Hanson et al. 2007). These dominant issues are challenging agriculturists to develop more sustainable management systems like no other time in history. To meet the food and nutritional needs of a growing population, agriculture will need to move beyond the past emphasis on productivity to encompass improved public health, social well-being and a sound environment (Dordas 2009).

The major objective of sustainable agriculture is to increase food production in a sustainable way and enhance food security. This is best accomplished through education initiatives, utilization of economic incentives and the development of appropriate and new technologies, thus ensuring stable supplies of nutritionally adequate food, access to those supplies by vulnerable groups, and production for markets; employment and income generation to alleviate poverty; and natural resource management and environmental protection. The priority must be on maintaining and improving the capacity of the higher potential agricultural lands to support an expanding population. However, conserving and rehabilitating the natural resources on lower potential lands in order to maintain sustainable man/land rations is also necessary (Figs. 1 and 2; Boon 2004).

Fig. 1 Preparing of sandy soils for cultivating and using drip irrigation in Shalateen district, Egypt. The extreme weather and very high temperature, very low soil organic matter content and scarcity of water are main common constraints in this area (Photo by H. El-Ramady)

Fig. 2 Preparing of heavy clay soil for cultivating using traditional tillage in Kafr El-Sheikh district, Egypt. The small tenures are most important restrictive for sustainable agriculture. Heavy soil texture, high salinity, high water table level and low soil organic matter content are also common constraints in this area (Photo by H. El-Ramady)

Table 2 List of 14 major degradation issues related to unsustainable agriculture based on the work of a Working Group on Sustainable Agriculture in Australia

No.	Issue	Possible causes
1	Decline in soil nutrients and biological activity	Rotations that lack grain/pasture legumes Inadequate testing for soil/plant nutrient levels Insufficient/inadequate fertilizer use
2	Soil structure decline	Excessive cultivation Bare soil and fallowing practices Overgrazing and loss of groundcover Animal/machinery traffic on wet soils
3	Soil acidification	Use of acidifying fertilizers Use of shallow-rooting pastures
4	Soil erosion	Poor cultivation techniques Overgrazing Insufficient vegetation cover Poor matching of enterprises to capability of land
5	Poor water quality	Inadequate effluent/waste disposal systems Contamination by fertilizers and pesticides Sediment and salt runoff in surface water
6	Soil salinity and waterlogging in irrigated areas	Inefficient and excessive water use under flood irrigation Deteriorating infrastructure Poor site selection for irrigation areas
7	Soil salinity and waterlogging in dryland areas	Excessive clearing of deep-rooted perennial native species causing rise in groundwater table
8	Pesticide residues and resistance	Overuse of pesticides Over-reliance on chemical control of crop weeds
9	Vegetation degradation	Over-grazing Poor use of grazing management to control weeds Poor weed control
10	Remnant vegetation decline	Insufficient use of fences Stock pressure on young stands
11	Fire management	Insufficient and excessive use of fire in certain grazing lands
12	Feral and native animals	Inadequate control of feral and native pest animals
13	Consequences of crop monoculture	Reliance on a single crop without rotation
14	Land use competition	Inadequate/inappropriate planning for land use Lack of dispute resolution

Adapted from Roberts (1995)

Since defining sustainable agriculture is so complex, an alternative is to define its converse state – unsustainability. Some scientists have indeed focused on identifying such a state. Based on the work of a Working Group on Sustainable Agriculture in Australia, 14 major degradation issues that are connected to unsustainable agriculture can be listed (Table 2). Included here are decline in soil productivity, increased risk of soil erosion, poor water quality, soil salinity, and vegetable degradation, among others. Many of these issues will apply to many parts of the

Table 3 Major threats to sustainability of agriculture

Threats	Indicators of threat	Effect on agriculture	Remediation period	Degree of threat
Soil erosion	Soil productivity; surface water pollution; sedimentation	Small	Years to decades	Small
Nutrient runoff	Surface and ground water pollution, eutrophication	None	Decades	Medium
Pesticide pollution	Ecosystem and human health	None	Decades	Medium
Wetland losses	Flooding and habitat loss	Small	Decades	Small
Water supply for agriculture	Loss of irrigation capability	Small	Decades to centuries	Small
Farmland loss	Urban runoff; Landscape values	Very small	Practically irreversible	Probably not a threat
Agricultural germplasm loss	Crop and livestock development; disease control	Large	Irreversible	Large
Global climate change	Changes in average temperature; precipitation; variability	Unknown	Centuries	Large

Adapted from Faeth (1997)

world, whether in developed or developing countries. For some of these issues, there are ameliorating practices. Since many of these are region/climate specific, more research is needed as to which one of these issues can be tackled under the sustainable agriculture paradigm (Kulshreshtha 2004).

Major threats to the sustainability of agriculture are shown in Table 3. Included in this list are some threats that have a relatively smaller level of incidence, and at the same time remedial measures can be applied to correct the situation over a shorter period of time. Soil erosion, loss of wetlands, and the availability of good quality water for agricultural use are classed under these types of threats. Then, there are changes that produce a slightly higher degree of threat to the sustainability of agriculture. This list includes nutrient run-off and pesticide pollution. The major threats to agriculture are from global climate change and loss of biodiversity. These threats will take literally centuries to remedy and may produce irreversible changes in our society's economic and social fabric. Some authors, for example, have suggested that under climate change, wheat production in south-western Saskatchewan will cease. These changes will undoubtedly affect the future of the entire region, and the livelihood of literally thousands of people (Kulshreshtha 2004).

An analysis of 95 agricultural project evaluations revealed a disturbing rate of failure (McGranaham et al. 1999). The cited reasons for failure include an emphasis on external technologies only, no participation by local people, ineffective training of professionals, institutions and no orientation towards the diversity of local conditions and the needs of local people. This evidence suggests four important principles for sustainability:

- *Imposed technologies are not sustainable*: if coercion or financial incentives are used to encourage people to adopt sustainable agriculture technologies (such as soil conservation, alley cropping, integrated pest management), then they are not likely to be sustainable;
- *Imposed institutions are not sustainable*: if new institutional structures are imposed, such as cooperatives or other groups at local level, or Project Management Units and other institutions at project level, then these were rarely sustained beyond the project;
- *Expensive technologies are not suitable*: if expensive external inputs, including subsidized inputs, machinery or high technology hardware are introduced with no thought to how they will be paid for, they too will not be sustained beyond the projects;
- *Sustainability does not equal fossilization or continuation of a thing or a practice forever*: rather it implies an enhanced capacity to adapt in the face of unexpected changes and emerging uncertainties (Boon 2004).

A more *sustainable agriculture* that can also serve to reduce malnutrition systematically pursues the following goals:

- *A thorough integration of natural processes* (such as nutrient cycling, nitrogen fixation, and pest-predator relationships) into agricultural production processes, thereby ensuring profitability and efficient food production;
- *A minimization of the use of those external and non-renewable inputs* with the potential to damage the environment or harm the health of farmers and consumers, and a targeted use of the remaining inputs, used with a view to minimizing costs;
- *The full participation of farmers and other rural people* in all processes of problem analysis, and technology development, adaptation and extension, leading to an increase in self-reliance amongst farmers and rural communities;
- *A greater use of local knowledge and practices*, including innovative approaches not yet fully understood by scientists or widely adopted by farmers;
- *The enhancement of nature's goods and services* and other public goods of the countryside (Boon 2004).

The pressure on finite soil resources for meeting the demands of the increase in population for food, feed, fiber, and fuel is likely to be exacerbated by several interactive factors. Notable among these factors are: (1) global warming, (2) soil degradation, (3) decline in fresh water supply along with pollution and contamination of water resources, (4) urban encroachment and industrialization, and (5) decrease in use efficiency and increase in price of energy-based input such as fertilizer and irrigation water. Despite the challenges, there is a vast scope for enhancing yields of food crops in developing countries. There is a strong need to alleviate biophysical and socioeconomic constraints to increase agronomic productivity in the developing countries of Asia and Africa. The *maximum yield potential* of an eco-region is determined by climatic factors – e.g., solar radiation, soil and air temperatures, and evapotranspiration – because there are no soil or plant-related constraints. In comparison, the *on-station crop yield*, through adoption of recommended management practices, is determined by a range of factors including drought stress, low soil fertility, farming system, and soil-water management options. The *attainable crop yield* is governed by social, economic, and institutional factors such as land tenure, market and infrastructure, and support services, etc. The *actual farm yield* is affected by the prevalent farming system, the type and severity of soil degradation, soil evaporation, and losses of water and nutrients from runoff and soil erosion. There is a large "yield gap" between the "on-farm" yield and "maximum yield potential" in developing countries. Bridging the yield gap necessitates the adoption of recommended practices for sustainable management of soil resources (Lal 2009c).

It could be concluded that, sustainable agriculture now appears to be a central science and it has risen to become one of the most important issues in agriculture. Sustainable agriculture is thus the best fitted science to solve current issues, to anticipate future negative impacts, and to define novel practices that will make the world safer for our children. The sustainability of agriculture has faced some of the most significant challenges in recent years. Major challenges include rapid growth of the human population, overdependence on fossil energy, global climate changes, and globalization.

2.1 Sustainability and Conservation of Natural Resources

The concept of sustainable agriculture – or rather the concept of sustainable development in agriculture – has become a widely accepted and supported scheme, encompassing both environmental and developmental aspects. There is no general answer to the question to which extent natural resources may be used or even consumed and to which extent the conservation of natural resources is obligatory. Within the manifold definitions of sustainable development indicated there is consensus that sustainable development implies the intergenerational transfer of natural capital. There is some disagreement, however, in terms of a clear interpretation and dimension of this long term transfer. And yet there are four basic objectives included in most definitions:

1. Concern to keep the environment intact in the long run,
2. Concern with regard to the welfare of coming generations,
3. Rejection of rapid population growth and
4. Concern whether it will be possible to maintain economic growth at the sight of diminishing resources.

Today, different indicators are available to measure trends and developments. Yet, the underlying individual economic understanding will strongly influence the result of any sustainability evaluation. An economist following the principles of "*weak sustainability*" for example will allow for a consumption of natural resources as long as the amount of natural resources used will be compensated for by newly created social or economic resources such as education or equipment. Natural resources consumed to produce modules for solar energy conversion will not be objected as the overall stock of natural and artificial capital will remain intact in the long run. In contrast, it is a prerequisite for "*strong sustainability*" that the natural and the artificial capital stock equally have to show consistent growth. In such a system compensation between the different stocks is not possible (Frangenberg 2007).

Agricultural ecosystems, i.e. land used for food and fiber production including the surrounding structural elements of the landscape such as hedges, small woodlands, ponds etc., are characterized by very complex interactions. By influencing the system – with planting, fertilization, crop protection measures and harvest – man inevitably influences natural resources such as biodiversity, soil and water. By creating favorable conditions for a crop, other plants and wildlife will find fewer of their natural habitats or at least less favorable living conditions. On the other hand, species dwelling on the crop grown in a particular year will suddenly find optimum conditions and show enormous population growth. This effect can be found in weeds which benefit from high nutrient contents in the soil as well as in aphids, insects or other pests which use crops as a natural host. In turn, natural enemies of these organisms might then find optimum living conditions and a new equilibrium develops. This cycle of ups and downs in populations of plants and wildlife characterizes agricultural ecosystems. To a certain extent, both farmers and nature gain from these complex interactions and in a lot of situations, the biodiversity in a landscape scale increases due to agricultural production compared with natural ecosystems in the same region (Frangenberg 2007).

Management of soil to improve sustainability is a complex matter that requires a thorough understanding of its physical, chemical, and biological attributes and their interactions. Proper soil management is a key component of sustainable agricultural production practices as it produces crops and animals that are healthier and less susceptible to pests and diseases. It provides a number of important ecosystem services, such as reduced nitrogen runoff and better water-holding capacity. Mismanagement of soil can result in physical, chemical, and biological degradation (Lal 2004). Soil management is critical to improving environmental sustainability of farming systems. Proper soil management practices aim to:

- Maintain or build up soil organic matter.
- Improve soil structure by increasing soil aggregates. The soil aggregates would in turn enhance water-holding capacity of soil.
- Minimize erosion. Reduction in wind erosion would improve air quality. Reduction in water and tillage erosion would improve water quality by reducing sediment loading.
- Enhance soil microbial activities and diversity.
- Reduce soil-borne pathogens (NRC 2010).

Without doubt, agricultural practices can have adverse effects on natural resources and thus reduce the ability of ecosystems to provide the goods and services mentioned above, because the ability of ecosystems to provide some services depends both on the number and type of species in an ecosystem (Tilman et al. 2002). With regard to biodiversity, it is therefore one major challenge for sustainable farming systems to allow field margins and headlands for nature conservation, to minimize side-effects of fertilization and crop protection beyond the field borders, to use thresholds for crop protection decisions, to grow a pattern of different crops and varieties within the cropping sequence and in adjacent fields, thus allowing for efficient production and nature conservation at the same time. Various studies have given evidence that organic as well as integrated farming can successfully combine nature conservation and agricultural production, even though organic farming needs to cultivate more land due to considerable lower yields per hectare, thus allowing for less undisturbed area to be conserved as natural habitats.

Apart from biodiversity as one major natural resource, soil and water can also be adversely affected by agricultural practices. First of all, increasing the productivity of agricultural lands by adding nutrients and organic matter, by ploughing deeper, by draining and irrigation, has improved soil fertility and hence productivity tremendously. However, plant species either adopted to acid soils or to low nutrient availability have lost their habitats on agricultural lands since nitrogen input exceeded about 50 kg per hectare and year. Accordingly, any agricultural production system which depends on nitrogen input in excess of 50 kg – and hence organic as well as Integrated Farming as well as conventional farming – will never be able to maintain the diversity of fauna and flora reported from the end of the eighteenth century. However, fertilizing above crop demand and improper crop protection practices can even lead to further effects such as nutrients and toxic substances in ground- and surface water, which in turn lead to purification costs for drinking water, and potentially decreasing fishery and recreational values. Excessive use of water for irrigation not only has shown negative effects on groundwater tables and surface water bodies but in part has also led to fatal salinization of soils, making them unsuitable for any regular plant and food production. Also, soil quality has in part been degraded due to erosion and or compaction in the past decades. Besides the damage which occurs on-site, in the case of erosion for example off-site damage such as eutrophication of aquatic habitats becomes evident. On-site, however, the agricultural soils affected by erosion have lost a good part of their production capacity due to lower fertility, reduced water retention capacity etc. Agriculture has always been the attempt to use natural resources to produce food and to make a living, based on the knowledge that the soil, the piece of land farmed cannot just be doubled or replaced but has to be conserved and treated properly for future generations. Modern and sustainable farming systems even try to be better, to be more efficient and more productive with less environmental impact. And yet mistakes have been and still are made, and damage has been and still is done. In the light of the growing world population, the conservation of natural resources – whilst using them efficiently – will remain one of the major challenges of mankind (Frangenberg 2007).

It could be summarized that soil management to improve sustainability is a complex matter that requires a thorough understanding of its physical, chemical, and biological attributes and their interactions. The proper soil management is a key component of sustainable agricultural production practices as it produces crops and animals that are healthier and less susceptible to pests and diseases.

2.2 Soil Functions and Sustainability

Three necessary conditions for sustaining the physical resource base include the following: (1) rate at which renewable resources are used should not exceed their rate of regeneration; (2) rate at which non-renewable resources are used should not exceed the rate at which sustainable renewable substitutes are developed; and, (3) rate of pollution emission should not exhaust the environment's assimilative capacity. Many of these aspects have now become a part of the sustainability proposals, including those in agriculture. It is important to point out that making the transition to sustainable agriculture is a process. Reaching this goal is the responsibility of all: farmers, laborers, policy makers, researchers, and consumers. Mitigation of threats to agronomic sustainability, which might emanate from greater stewardship by farmers, is unlikely, insofar as their Micro-economic Sustainability is under great pressure. Fewer and fewer farms struggle to retain a viable financial position against the pressures of the 'cost-price squeeze' inflicted by agri-businesses, governments, and consumers, all wanting cheap food. Sustainable agriculture requires both a change in the economic and institutional framework and farmers' motivation and values. Appropriate intervention by the governments in areas such as market access, infrastructure development, research and extension, could make a critical difference in the process of development of sustainable agriculture the world over.

Sustainable agriculture is a value-laden concept – it involves a deep commitment to the land, to conserve lifestyles, to the rejuvenation of rural communities and associated infrastructure, to the preservation of the environment, and to economic systems that place value on human fulfillment and discourage emphasis on mere commodity exchange in market place (Kulshreshtha 2004).

Agriculture worldwide faces daunting challenges because of increasing population growth and changing food consumption patterns, natural resource scarcity, environmental degradation, climate change, and global economic restructuring. Yet, at the same time, there are unprecedented hopeful changes and opportunities for the future, including a remarkable emergence of innovations in farming practices and systems and technological advances that have generated promising results for improving agricultural sustainability and an increase in consciousness and concern by consumers about the sources of their food and how it is produced. Sustainability has been described as the ability to meet core societal needs in a way that can be maintained indefinitely without significant negative effects. Accordingly, development of a sustainable agricultural production system requires defining the core societal needs from agriculture, a process that will require a collective vision of what the future characteristics of agriculture should be. Improving sustainability is a process that moves farming systems along a trajectory toward meeting various socially determined sustainability goals as opposed to achieving any particular end state. Agricultural sustainability is defined by four generally agreed upon goals:

- Satisfy human food, feed, and fiber needs, and contribute to biofuel needs.
- Enhance environmental quality and the resource base.
- Sustain the economic viability of agriculture.
- Enhance the quality of life for farmers, farm workers, and society as a whole.

The sustainability of a farming practice or system could be evaluated on the basis of how well it meets various societal goals or objectives. To be sustainable, a farming system needs to be sufficiently productive, robust (that is, be able to continue to meet the goals in the face of stresses and fluctuating conditions), use resources efficiently, and balance the four goals. Table 4 illustrates the relationships between the two sustainability goals and sub-goals, management activities and specific practices that can be used to reach the goals, and a selection of potential indicators that are or could be used to assess progress toward specific goals (Figs. 3, 4 and 5; NRC 2010).

The basic aim of sound soil fertility management is to enhance crop productivity, to sustain it, and to keep the soils in good health – physically, chemically and biologically. *Soil fertility* is a complex quality of soils that is closest to plant nutrient management. It is the component of overall soil productivity that deals with its available nutrient status, and its ability to provide nutrients out of its own reserves and through external applications for crop production (Table 5).

It combines several soil properties (biological, chemical and physical), all of which affect directly or indirectly nutrient dynamics and availability. Soil fertility is a manageable soil property and its management is of utmost importance for optimizing crop nutrition on both a short- and a long-term basis to achieve sustainable crop production. *Soil productivity* is the ability of a soil to support crop production determined by the entire spectrum of its physical, chemical and biological attributes. Soil fertility is only one aspect of soil productivity but it is a very important one. For example, a soil may be very fertile, but produce only little vegetation because of a lack of water or unfavorable temperature. Even under suitable climate conditions, soils vary in their capacity to create a suitable environment for plant roots. For the farmer, the decisive property of soils is their chemical fertility and physical condition, which determines their potential to produce crops. Good natural or improved soil fertility is essential for successful cropping. It is the foundation on which all input-based high-production systems can be built (FAO 2006).

The basic requirements of good soil fertility include:

- Optimal soil reaction within a practical range;
- Sufficient organic matter by applying organic manures for improved soil structure, water storage capacity, nutrient supply and satisfactory activity of soil organisms;
- A stable porous soil structure with no compact layer, which restricts root growth;
- Good drainage;
- Water availability, especially during periods of water stress and long dry spells;
- Removal or neutralization of toxic substances, e.g. in strongly acid (Al), polluted (toxic heavy metals) or saline/alkali soils (excess chloride, Na, etc.).

Soils that are very rich in a nutrient and are able to release it at an acceptable rate in relation to crop demand would generally need its application only to the extent of crop removal replacement. This calls for periodic monitoring of the soil nutrient status because the "very rich" condition does not last indefinitely, particularly under intensive cropping. At the same time, it is necessary to differentiate between nutrients that are mainly applied on a crop-to-crop basis, such as N, and nutrients that leave a significant residual effect. The latter are not to be applied to each crop but on

Table 4 An Illustration of activities and practices used to achieve agroecological sustainability goals and of indicators for evaluating sustainability

Agroecological sustainability goals	Examples of indicators	Activity	Examples of practices
1. Satisfy human food, fiber, feed, and fuel needs			
a. Sustain adequate crop production	Yield per unit area, yield per unit resource use (energy, water, and nutrients)	Crop management	Fertility, pest, and water management. Plant breeding and genetic modification to improve yield and stress tolerance
		Plant breeding	Crops bred for increased resistance to biotic and abiotic stresses, enhanced nutrient use efficiency, and yield stability
b. Sustain adequate animal production	Production per unit land, production per animal, production per unit resource use (energy, water, nutrients), mortality, duration of productive life, conversion of feedstuff to human edible products, animal health	Animal husbandry	Use of local feedstuffs, careful use of resources (labor, water, energy), breeding for increasing feed efficiency, animal health and welfare, herd health management (disease prevention), improved housing environments, judicious use of antibiotics, waste management, manure applications to field, and advanced treatment technologies for manure
2. Maintain and enhance environmental quality and resource base			
a. Maintain or improve soil quality	Soil nutrient levels, nutrient use efficiency	Soil-fertility management	Fertilizer and organic amendment application, use of soil and tissue tests, nutrient budget calculations
	Soil organic matter content, microbial and macrofaunal populations and communities	Organic matter management	Conservation tillage, organic amendments, composts, green manure
	Soil physical structure such as bulk density, water holding capacity, aggregate stability, porosity, water infiltration rate	Organic matter management	Conservation tillage, organic amendments, compost, green manure
b. Maintain or improve water quality	Fertility inputs, field or farm nutrient budget balances, nutrient, pesticide, and pathogen concentrations in water courses, leaching estimates, nutrient or water model outputs	Soil-fertility management	Use of nutrient budgets, use of slow release fertilizers and organic amendments, plant nutrient tissue tests, soil nutrient tests, manure disposal

	Ground cover, USLE[a], direct measures of nutrient, sediment and pesticide fluxes, area in cover crops or perennial vegetation, soil aggregate stability, water-holding capacity, porosity, water infiltration rate	Crop vegetation management, nutrient management, and erosion and runoff control	Plant cover crops, use of organic amendments, soil and tissue tests, conservation tillage, mulches, grass waterways, buffer strips, riparian vegetation, treatment wetlands
c. Conserve fresh water supply	Crop water use efficiency, water consumption, ground water overdraft, pumping rates	Irrigation management	Drip irrigation, irrigation scheduling based on evapotransporation or soil moisture
d. Reduce pesticide use	Pest populations, natural enemy populations, weed biomass, percent weed cover, vegetation diversity, presence of perennial habitat	Management of pest complex	Integrated pest management practices, biological and ecological approaches, soil organic matter management, crop breeding
e. Conserve and enhance biodiversity	Biodiversity estimates (for example, number of plant species, number of species within selected animal groups, habitat diversity, landscape complexity, and connectivity)	Habitat management	In-field insectaries, hedgerows, riparian vegetation, habitat corridors, natural habitat fragments

Adapted from NRC (2010)

[a] *USLE* Universal soil loss equation

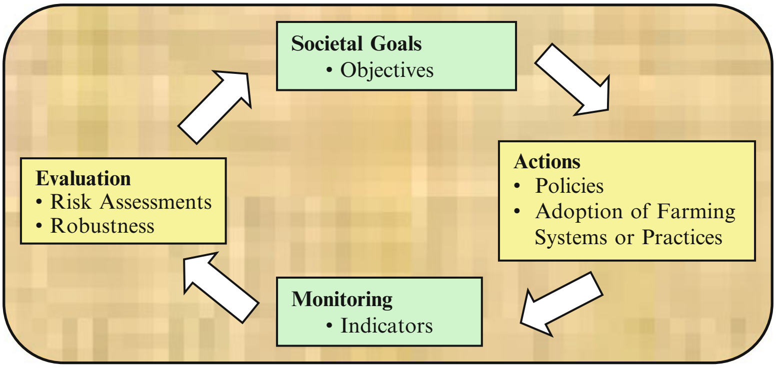

Fig. 3 Adaptive management for sustainability of agricultural farming systems within different items, i.e., societal goals, actions, monitoring and evaluation (Adapted from NRC 2010)

Fig. 4 Drip irrigation for both horticultural and field crops is already used in Marsa Alam district, Egypt. Similar problems in Shalateen are existed and suffer from them in Marsa Alam (Photo by H. El-Ramady)

a cropping-system basis (P, S, Mg and micronutrients such as Zn and Cu). Large applications of Mg resulting from the use of dolomitic limestone can last for several years. In deciding the frequency with which such nutrients need to be applied, the degree of their fixation by soil constituents needs to be taken into account. The system is a dynamic one and it should be managed accordingly (Roy et al. 2006).

Fig. 5 Drip irrigation for both horticultural and field crops is already used in Nubaria district, Egypt. Faba bean and other vegetable crops are cultivated between citrus tree rows (intercropping). The most problems in this area represent very low soil organic matter content, shortage of water and high soil salinity (Photo by H. El-Ramady)

Table 5 General soil test limits used for classifying soils into different fertility classes, where the different categories of soil fertility with method are listed

		General fertility class*		
Nutrient	Method/extractant	Low	Medium	High
N (% organic C)	Organic carbon	<0.5	0.5–0.75	>0.75
N (kg ha^{-1})	Alkaline permanganate	<280	280–560	>560
P_2O_5 (kg ha^{-1})	Sodium bicarbonate	<23	23–56	>56
K_2O (kg ha^{-1})	Ammonium acetate	<130	130–335	>335
S (kg ha^{-1})	Heat soluble, $CaCl_2$	<20	20–40	>40
Ca (% of CEC)	Ammonium acetate	<25		
Mg (% of CEC)	Ammonium acetate	<4		
Zn (μg g^{-1})	DTPA	<0.6	0.6–1.2	>1.2
Mn (μg g^{-1})	DTPA	<3.0		
Cu (μg g^{-1})	DTPA/ammonium acetate	<0.2		
Fe (μg g^{-1})	DTPA	<2.5–4.5		
Fe (μg g^{-1})	Ammonium acetate	<2.0		
B (μg g^{-1})	Hot water	<0.5		
Mo (μg g^{-1})	Ammonium oxalate	<0.2		

Adapted from FAO (2006a)

*Very general limits based on several published Indian sources (Tandon 2004)

It could be conclude that agriculture worldwide faces daunting challenges because of increasing population growth and changing food consumption patterns, natural resource scarcity, environmental degradation, climate changes, and global economic restructuring. It is important to point out that making the transition to sustainable agriculture is a process. Reaching this goal is the responsibility of all: farmers, laborers, policy makers, researchers, and consumers.

2.3 Environmental Soil Management and Sustainable Development

Environmental soil management is fundamental to the sustainability of diverse rangeland ecosystems. Key concepts necessary for rangeland soil management include dynamic and static soil properties, resilience to both anthropogenic and natural including climate changes and extreme events stressors, soil-plant-animal feedbacks and management at multiple scales, many of which are not correlated with existing management units. Rangeland soils can be managed to support a broad range of ecosystem services, including forage production, wildlife habitat, biodiversity conservation, water quantity and quality, air quality and carbon sequestration. In some cases, managing for one service can be used to simultaneously enhance other services. Environmental soil degradation is caused by both mismanagement associated with overgrazing, and by land conversion to other uses, including crop production, urbanization and energy development. Rangeland remediation usually focuses on the plant community and few resources are usually available to directly improve soil quality, but integrated approaches to soil and vegetation management can be successful. Soil management is more likely to be addressed if soils are included in assessment and monitoring programs. Finally, a system is introduced to help determine when environmental soil management should be the focus of sustainable development projects, and when resources are better allocated to address other issues (Figs. 6 and 7; Herrick 2009).

On a global scale, agriculture was very successful in meeting a growing demand for food during the latter half of the twentieth century. Yields per hectare of basic crops such as corn, wheat, and rice increased dramatically, food prices declined, the rate of increase in food production was generally able to keep up with the rate of population growth, and chronic hunger diminished. This boost in food production was due mainly to scientific advances and technological innovations, including the development of new plant varieties, the use of fertilizers and pesticides, and the growth of extensive infrastructures for irrigation. But the elements of the food crisis noted above are signs that this era of ever-rising food production may be coming to an end. We may be approaching a limit in the amount of food that we can produce relatively inexpensively, given the limited amount of arable land left on the earth and the degraded condition of much that is already being cropped (Gliessman 2010).

Fig. 6 The grapevines are cultivated in raised-bed in Nubaria district, Egypt to avoid the high soil salinity. The weeds are growing between rows of grapes, which manually control (Photo by H. El-Ramady)

Fig. 7 The high soil salinity formed crust and by cultivation the soil will be changed using special treatments. The *double irrigation lines* are used in raised-bed to overcome soil salinity in Nubaria district, Egypt (Photo by H. El-Ramady)

Soil management is often treated as an independent discipline, leading to the development of linear, engineering approaches that ignore many of the feedbacks and interactions with plants and animals on which rangeland soils depend. Rangeland soils cannot be managed independently of rangeland vegetation but also impossible to develop successful management strategies independent of the socioeconomic factors that determine which ecosystem services provided by rangelands in a particular area are most highly valued, and the costs of potential inputs. Development and adoption of sustainable land management strategies also depend on the knowledge of the individuals who are responsible for their implementation.

A recently developed 'Drylands Development Paradigm' (DDP) identifies five principles that are equally relevant to soil management of more mesic rangeland ecosystems. These principles have a number of implications for ensuring that environmental soil management is an integral and effective part of sustainable development. **The first** is that human and ecological (including soil) drivers of degradation and recovery need to be considered simultaneously. **The second** is that, while there are a virtually infinite number of relevant processes and variables, there is a limited set of variables that must be addressed to increase sustainability. These variables, which typically change relatively slowly, often, but not always, include soil properties and processes. **The third** is that the costs of remediation increase non-linearly with land degradation. The resulting biophysical and socioeconomic thresholds must be identified and avoided to minimize remediation costs. **The fourth** is that these processes and properties must be addressed at the appropriate scale or scales. Improving soil structure in a one hectare paddock will have no long-term impact if gully development associated with degradation at the landscape scale is not addressed. **Finally**, local environmental knowledge, including knowledge about soil variability, is essential to developing successful strategies. Together, these principles can help managers determine when soil degradation must be addressed directly, and when addressing other issues, such markets for soil enhancing crops, is more likely to be successful (Herrick 2009).

Therefore, it could be summarized that environmental soil management is fundamental to the sustainability of diverse rangeland ecosystems. Soil management is often treated as an independent discipline, leading to the development of linear, engineering approaches that ignore many of the feedbacks and interactions with plants and animals on which rangeland soils depend.

2.4 Human Development, Food and Agriculture

Human development is a complex concept which incorporates various aspects of well-being and opportunities for people. The Pakistani economist ***Mahbub ul Haq*** has defined human development the following way: "*The basic purpose of development is to enlarge people's choices. In principle, these choices can be infinite and can change over time. People often value achievements that do not show up at all, or not immediately, in income or growth figures: greater access to knowledge, better* *nutrition and health services, more secure livelihoods, security against crime and physical violence, satisfying leisure hours, political and cultural freedoms and sense of participation in community activities. The objective of development is to create an enabling environment for people to enjoy long, healthy and creative lives.*" In this understanding human development is an economic theory which merges ideas from ecological economics, sustainable development, welfare economics, and feminist economics. It seeks to avoid normative politics and judgments by only justifying its theses strictly in ecology, economics and sound social science, and by working within a context of globalization. Accordingly, human development theory is a major synthesis that is probably neither confined within the bounds of conventional economics or political science, nor even the political economy that relates the two (Christen 2007).

Since agricultural production and the supply with a sufficient amount of high quality food is a major prerequisite in human development, these topics have been included in recent reports. For millions of small farmers, pastoralists and agricultural laborers the stakes in the gamble are far higher. Variations in rainfall, or disruptions in water supply, can make the difference between adequate nutrition and hunger, health and sickness and – ultimately – life and death. Water security in agriculture pervades all aspects of human development. Land and water are two key assets on which poor people depend for their livelihoods, usually far more than do people who are better off. Water cannot be considered in isolation from wider capabilities such as health and education, or from access to other productive assets, including land, capital and infrastructure. But water insecurity represents a powerful risk factor for poverty and vulnerability. Livelihoods comprise the capabilities and assets that people need to make a living and maintain their well-being. In rural areas water plays a crucial role for some obvious reasons. Like land, it is part of the natural capital base that underpins the production systems that sustain livelihoods. Access to a reliable supply of water makes it possible for people to diversify their livelihoods, increase productivity and reduce the risks associated with drought. It enables producers to enter higher value-added areas of production and creates income and employment, and it gives people the security to undertake investments. The links between rural livelihoods, water and global poverty reduction efforts are immediately apparent. Some three-quarters of all people surviving on less than $1 a day live in rural areas, where their livelihoods are dependent on agriculture. Smallholder farmers and agricultural laborers also account for about two-thirds of the world's 830 million malnourished people. The water security-livelihood nexus helps to explain the widely observed relationship between water and poverty (Christen 2007).

The increasing population in the developing world will inevitably dramatically increase the demand for food and thus put strong pressure on agriculture to increase production, which can be either done by using a greater proportion of land or by increasing productivity per area. The supply with sufficient water is only one aspect of the relation between human development on the one hand and food and agriculture on the other. Another strong link, underlined by the Millennium Development Goals of the United Nations, which in 2000 adopted the Millennium Declaration, is a renewed commitment to human development. The Declaration includes eight *Millennium*

Development Goals (MDGs), each with quantified targets, to motivate the international community and provide an accountability mechanism for actions taken to enable millions of poor people to improve their livelihoods. The MDGs are as follows:

1. Eradicate extreme poverty and hunger
2. Achieve universal primary education
3. Promote gender equality and empower women
4. Reduce child mortality
5. Improve maternal health
6. Combat human immunodeficiency virus/acquired immune deficiency syndrome (HIV/AIDS), malaria, and other diseases
7. Ensure environmental sustainability
8. Develop a global partnership for development (Christen 2007).

Therefore, it could be concluded that agricultural production and the supply with a sufficient amount of high quality food is a major prerequisite in human development. The supply with sufficient water is only one aspect of the relation between human development on the one hand and food and agriculture on the other.

2.5 Water Use for Food Production

Water is essential to human development. It is a substantial element of the natural environment, and intrinsically connected with all its interactive processes. Interesting dynamic relations also exist between water supply and water quality, however. These affect key human development activities, including energy generation and agricultural food production. Agriculture, as well as being crucial to food production, is also the main water-consuming human activity in most regions of the world. It is known worldwide that water is an especially important natural element because of its interactions with life-related issues, since it is needed to support life. Energy, food, and the environment in general are inseparably related to its presence and quality. Ironically, water is the first natural resource to be affected by poor practice in the production of either energy or food. Finally, water is an "environment" itself, being the support milieu for many ecosystems. As a resource, it is one of the most fragile and sensitive of all to pollution and contamination (Donoso and Vargas 2004).

Life as we know it is not possible without the many biophysical and chemical services provided by water. All the organic and mineral substances in living organisms contain water, are surrounded by water, and are transported by it within the organic body. Thus, 80 % or more of a typical plant or animal is composed of water. Besides the water it contains and by which it is surrounded, water as well as its individual constituents of hydrogen and oxygen are major components of biomass. Availability of water is basic in the generation of all biomass, including food for humans. No ecosystem can exist without water and this is also true for the artificial, managed, or manipulated ecosystems used by man for the production of food and other benefits and commodities, called "agro-ecosystems" (Figs. 8 and 9; Klohn 2004).

Fig. 8 The main irrigation canal is lining in Nubaria district, Egypt because of the very high infiltration rate or low soil water retention of sandy soils. Drip and sprinkler irrigation are common in this area (Photo by H. El-Ramady)

Fig. 9 The main irrigation canal is lined using the agricultural water management near the grapevine in Nubaria district, Egypt (Photo by H. El-Ramady)

Most food produced worldwide depends on agriculture; “wild” ecosystems could produce not more than food for 10 % of the global population. A main input to agricultural production is water, either in the form of rainfall or of irrigation water applied to crops. However, a large number of people (13 % of global population, about 800 million) do not have access to sufficient and adequate food for their nutritional requirements. In particular, the impact of food insecurity on children, in terms of stunted bodies, minds and hopes, is devastating. The cause of food insecurity is poverty, an expression of lack of monetary income, social protection networks, or access to the land and water necessary for self-sustenance. A majority of poor and food-insecure people are rural people who can hardly get jobs in the industry and services sectors. Overall agricultural production constraints, including water scarcity, are not as yet a cause of food insecurity: more food could be produced on the globe if the poor could exercise demand for it. Various national policy measures addressing removal of the causes of poverty can contribute to improvement of the food security of disadvantaged groups. Such policies need to be pro-poor and redress existing entrenched inequity in terms of trade, government-provided services and gender. Large-scale irrigation projects funded through public debt have often been hijacked through corruption, graft and rent-seeking. Small-scale irrigation offers better opportunities for empowering the poor when these obtain secure rights to land and water, and consequent access to credit and extension services. Groundwater, allowing control of the resource at the farm and reduced vulnerability to natural hazards, provides food security benefits to individual farmers who can access it. Man-made agricultural systems claim sizeable amounts of water and other environmental resources and much larger efforts by society will be required to ensure that agriculture finds a sustainable place in the environment in which it is embedded (Klohn 2004).

Globally, the world has enough water; however, the water is unevenly distributed. Industries and households are increasingly demanding water at the expense of agriculture. Agriculture uses approximately 70 % of the total amount of water withdrawn to supply our current food needs. By 2030 the Food and Agriculture Organisation estimates that we will require 60 % more food to feed the world’s ballooning population. If agricultural production is to be sustainable, water resources must be used more efficiently while still increasing agricultural productivity. By using a range of agricultural techniques and technologies such as modern irrigation techniques, integrated pest management and biotechnology, farmers can produce higher yields with higher quality produce while making the most of precious water supplies (Metzidakis et al. 2008).

World agriculture consumes approximately 70 % of freshwater withdrawn per year. About 17 % of the world’s cropland is irrigated but produces 40 % of the world’s food. Worldwide, the amount of irrigated land is slowly expanding, even though salinization, water logging, and silting continue to diminish productivity. Despite a small annual increase in total irrigated areas, the per capita irrigated area has been declining since 1990, due to rapid population growth. Specifically, global irrigation per capita has declined nearly 10 % during the past decade, while in the U.S. irrigated land per capita has remained constant at about 0.08 ha. Water for

Table 6 Energy savings and production potential from irrigation water management

Conservation	Resource savings energy On-farm ($ per acre)	Total	Costs reduction (million $)
Improving pumping system efficiency 10 % on 16 million acres	15	80 million gallons	240
Conversion of medium pressure sprinkler system to low	40	560 Kwhr/acre	390
Conversion of high pressure sprinkler system to low	55	770 Kwhr/acre	120

Adapted from USDA-NRCS (2006)
USDA-NRCS U.S. Department of Agriculture National Resource Conservation Service

agriculture covers a wide range of consumptive and non-consumptive water uses in all the agricultural sub-sectors related to ethical conflicts and significant social, economic, and environmental issues. Agricultural water represents the dominant water use in the form of pumping for irrigation or rainwater and soil moisture in croplands and forests. Evaporation from freshwater bodies and wetlands is important for biodiversity and inland and marine fisheries. Irrigation uses about 70 % of total globally extracted water volumes, estimated at 6,800 km^3 $year^{-1}$, while total agricultural use represents about 92 % of total uses of flowing water and rainwater (25,000 km^3 $year^{-1}$; García-Tejero et al. 2011).

Agricultural water management aims at obtaining good crop yields, income, and food security, while limiting damage to the environment and problems with water-related diseases. It also aims at understanding the patterns of water use at different scales, so that water savings can be made and new resources identified. There are globally 270 million hectares, close to 20 % of all agricultural land, where water is managed for its application to crops. Somewhat loosely, this article uses the word "*irrigation*" and the more cumbersome term "*agricultural water management*" interchangeably. Because irrigation is the dominant form of water use, measures that improve the efficiency of water application and minimize water loss are most effective in conserving water and energy in regions facing limited supply (Table 6).

Food stems from three main sources: agricultural crops, livestock, and fisheries. Crop agriculture accounts for nearly 80 % of all food consumed, while livestock and fishery products increasingly also depend on agricultural crops. It has been estimated that non-agricultural resources, that is, food obtained from gathering, hunting, and fishing, cannot feed more than some 600 million people, about 10 % of the world population in 2000. In particular, oceanic fisheries, a major source of "wild" food, have reached a ceiling with the use of modern technology. Therefore, crop takes a central position in the analysis of food supply. However, fishing and gathering continues to be the basis of livelihood for a large number of people who have no other income. Freshwater fisheries as an environmental resource have been instrumental for the survival of millions of refuges from warfare, drought, and environmental degradation. All organic matter, whether of animal or vegetal origin, is based on energy fixed by plants through the photosynthesis process: animals cannot synthesize organic matter but only re-elaborate existing biomass. The photosynthesis process takes as inputs carbon dioxide, water, and solar energy in the presence of chlorophyll, and produces compounds of the chemical family of sugars, while releasing oxygen. The sugars are later used as raw materials for elaboration, within the plant, of other organic substances such as fats, proteins, and nucleic acids, which are basically composed of carbon, hydrogen, and oxygen but can also contain nitrogen, phosphorus, and sulfur. The metallic elements sodium, potassium, calcium, and magnesium carry out indispensable functions for life and are often present in biomass. Some twenty other elements are present in living beings in trace quantities and have a role in various biochemical reactions. All the main and trace elements are absorbed through the roots of plants as salts dissolved in water; if the needed elements are not available, vegetal growth is stunted (Klohn 2004).

Agricultural water use is basically consumptive: transpiration does not necessarily substrate water totally and immediately from the resources of the river basin – although of course it is not lost to the hydrological cycle and will eventually become available again somewhere through precipitation. Transpiration from plant associations tends to create a fresh, humid local microclimate; therefore, water is not necessarily subtracted immediately or totally upon transpiration from the river basin resources. Evaporation from inert surfaces, where it does not contribute to biomass production, is a net loss of water and reducing it is one of the avenues for saving water. Organic substances used by plants and animals for their own bodies are re-used, when they die, by other plants and animals. Dead organic material, dispersed in the soil, contains carbon, hydrogen, oxygen, nitrogen, and all the other elements that were present in the living organism. Dead organic material decomposes through using oxygen and freeing water, carbon dioxide, and mineral salts. In a stable, balanced ecosystem, everything is recycled and the quantity of organic matter produced every year by photosynthesis equals the quantity that is freed through oxidation by the living organisms and decomposition of the dead organic matter. Certain ecosystems can accumulate organic matter: coal deposits, for example, were generated in past times by such ecosystems. Conversely, accumulated biomass can be destroyed through decomposition and burning, returning water; mineral salts, nitrogen, and carbon dioxide, while using oxygen – but this process can last only as long as stored biomass is available. Ecosystem fertility depends on the duration of the vegetative period, when the temperature and sunshine requirements are met. Fertility also depends on availability of sufficient water and nutrients provided by the environment. Recycling organic matter with its nutrients is a basic principle of sustainable agriculture (Klohn 2004).

Freshwater for agricultural irrigation is taken from water bodies such as rivers, lakes, or groundwater and applied to the crop in addition to any natural rainfall during the vegetative period. The vegetative period does not necessarily coincide with the high river flow period of the hydrological cycle, and therefore irrigation generally raises the need for water storage. Water can be stored in the soil profile, in underground aquifers, or in surface water impoundments. Plants such as cactus store water in their own tissues. For various reasons, surface water reservoirs – river dams – have become the dominant form of water storage. With or without storage, much water loss takes place in the process of moving it from the intake to the field. Similarly, once water is applied to the field, it may evaporate from the ground surface or percolate through the soil without reaching the roots of the crop, or reaching the roots at a time the crop did not need it and therefore is wasted without productive benefit. Many irrigation projects were implemented at a time when little or no economic value was attached to water, it being perceived as a “free” good, and they are notoriously inefficient in the way they handle the resource. Saving water is a matter of good management, but not all water savings are equal: some are said to be “wet”, others “dry”. Preventing water from leaking into the ground, where it would recharge the water table and from where it can be withdrawn by other users, does not add to the resource in the river basin and is described as “dry.” However, preventing unproductive evaporation and water salinization results in effective “wet” water savings (Klohn 2004).

Therefore, it could be summarized that water is a substantial element of the natural environment, and intrinsically connected with all its interactive processes. It is well known worldwide that water is an especially important natural element because of its interactions with life-related issues, since it is needed to support life. Energy, food, and the environment in general are inseparably related to its presence and quality.

2.6 The Outlook of Water for Agriculture

Water is the prime substance needed for agricultural production. It is also an “environment” in its own right, nurturing thousands of species that humans use for food. It may become polluted, however, as a consequence of different practices related to food production, especially in agriculture. Water in oceans, rivers, lakes, and aquifers may be affected. Moreover excess water, and shortages due to floods and droughts, may lead to agricultural harvest losses, and the drowning or dehydration of edible species. Today’s world population is around seven billion people. In order to understand and help satisfy the feeding requirements of this number of inhabitants, world specialists in agencies such as the FAO carry out comparative studies of world resources and requirements. In these studies, agriculture is taken to be a primary source for food. One of these studies estimated that around 800 million people in the developing world do not have enough to eat (FAO 2000a,b). In the World Food Summit of 1999, it was agreed to attempt a 50 % reduction in this number by the year 2015. Although identification of these needs was itself a positive step, more detailed analysis has shown that momentum is too slow, and progress too uneven, for this goal to be achieved (FAO 2000c). There is no single prescription for fighting hunger: policies and strategies must address both the causes and effects of food insecurity, in order to build an appropriate framework for concrete actions. In the meantime, scientists are engaged in research programs and projects to assess the interactions between water quality and supply and agriculture (Donoso and Vargas 2004).

Global “*back of the envelope*” calculations can convey a general feeling about a situation and the complex relations involved, but do not apply to any specific location in particular: the world is very diverse and people, water, and agricultural land are unevenly distributed. Water scarcity is not universal and is only of concern to everyone because trade allows movement of food from surplus to deficit areas. Statistical data on agriculture, nutrition, and water are collected at the country level by FAO and various other international agencies. Countries, however, can be far from agriculturally homogeneous, the data are hard to collect and to evaluate, their reliability is uneven, and the data are not always complete, neither is all the desirable information covered in data collection. Nevertheless, global agricultural statistics provide a reasonably realistic picture at country and regional level. According to the FAO, and in accordance with population projections, world crop production will grow at an average 1.3 % per annum between the years 2000 and 2030. During 1997–2000, the growth rate was 2.2 %. The decrease reflects decreasing demographic growth rates and also the fact that a growing number of countries will reach a food intake ceiling, thus not generating more demand. Growth in crop production will be stronger in developing countries (1.6 % per annum) than in developed countries (0.8 % per annum), reflecting higher demographic growth rates and the dependence of many developing countries on local agriculture, both for food supplies and for an overwhelming part of their economy.

By 2030, developing countries would account for almost three-quarters of world crop production, up from two-thirds in the last part of the twentieth century. Growth in crop production is projected to exceed demographic growth, reflecting better nutrition and a dietary shift towards more meat consumption. About 80 % of the projected growth in crop production in developing countries would come on account of intensification in the form of yield increases (69 %) and higher cropping intensities (12 %). At present, it is estimated that irrigated agriculture, with 20 % of all arable land, produces about 40 % of all crops and almost 60 % of cereals. In developing countries, irrigated agriculture accounts for 38 % of the increase in arable land and over 70 % of the increment in cereal production. Clearly, the importance of irrigated agriculture will continue increasing. Developing countries accounted for three-quarters of world total irrigated area in 2000 and it is therefore reasonable to assume that the world irrigation scene will remain dominated by actions in developing countries. The FAO studied the situation in a selection of 93 developing countries; irrigation in these countries is projected to expand by 23 % (45 million hectares) until 2030. On this basis, by 2030, 60 % of all land with irrigation potential (402 million hectares) would be in use. The projected net increase in arable irrigated land of 45 million hectares is less than half of the increase over the preceding 34 years (94 million ha). In terms of annual growth rate, this is 0.6 %, well below the 1.9 % for the 34-year period covered by the statistical record. The projected slowdown reflects the increasing scarcity of suitable areas for irrigation (including scarcity of water resources) and the rising costs of irrigation investment. Most of the expansion of irrigated land is achieved by converting land already in use in rain-fed agriculture, or land with rain-fed production potential but not yet in use, into irrigated land (Klohn 2004).

During the period 1996–2030, irrigation water withdrawal in these 93 countries is expected to grow by 12 %, while the irrigated area, as mentioned before, is expected to increase by 23 %. The difference is explained mostly by improvement in irrigation efficiency, leading to reduction in amounts of water needed for irrigation. Indeed, looking at the water balance situation in the selected countries, one finds that irrigation efficiency in many of them is low and even minor improvements can free major amounts of water. A small part of the expected reduction in water demand per hectare derives from changes in cropping patterns in some countries, where a shift from rice to wheat production is expected. Wheat production usually requires only half as much water as production of rice. Relying on FAO figures and estimates, food demand in 2030 will be satisfied at a price level that will not have sharply increased from the historically low levels and within the available water resources. Water scarcity is not expected to drive up the prices of food in this period. In other words, the agricultural aspect of the water crisis is already on its way to a managed solution for the people that have access to the food market. This does not yet address the plight of people who are too poor to buy or to produce the food they need: if they cannot eat to satisfy their hunger, it is not because the world is running out of water. However, if poverty is reduced and food prices do not increase dramatically, there is a good chance of improving the nutritional situation of the world and to put an end to malnourishment (Klohn 2004).

Water availability and quality are closely related to the amount and frequency of rainfall. The dry-land areas of the world are among the regions most vulnerable to climate change. A timely signaling of the impact of climate change, including changes in climate variability and identification of adaptation strategies in this complex environment are crucial. Clearly, adaptation to environmental change is not new, as changes and variations in climate and other environmental factors have occurred naturally. Both human and natural systems have had to adapt to these changing conditions. Climate change will increase the probability of extreme weather conditions, leading to catastrophic income shortfalls. Agricultural research plays an important role in developing technologies that perform well under drought conditions. International agreements on climate change may be exploited for redefining certain policies. Finally, there is plenty of scope for improving scientific research on climate change by extending research networks, by improving existing models, and by increasing the research geographic area (García-Tejero et al. 2011).

Therefore, it could be concluded that water is the prime substance needed for agricultural production. It is also an environment in its own right, nurturing thousands of species that humans use for food and its availability and quality are closely related to the amount and frequency of rainfall. Excess water and shortages due to floods and droughts, may lead to agricultural harvest losses, and the drowning or dehydration of edible species.

2.7 Food Security and Insecurity

Food security implies physical, social, and economic access to sufficient, safe, and nutritious food by all people at all times to meet their dietary and food preferences for an active and healthy life. In this regard, food security has four distinct components:

1. Food production through improved and sustainable management of soil, water, crops, livestock, and other components of farming systems;
2. Food stability as determined by reliable agronomic production in view of biotic and abiotic stresses including the probably adverse effects of climate change;
3. Food access as determined by the economic/financial capacity of the household and
4. Food effectiveness as determined by safety and health standards. With these criteria, there is a serious global food crisis right now, especially from 2006 to 2009 as it was during the 1960s.

Furthermore, there are even bigger challenges of food insecurity by 2025 and 2050 because of:

1. Increase in global population, of which 99.9 % of the future increase will occur in developing countries;
2. Increase in prices of food staples because of the diversion of grains such as corn and soybean to bioethanol production;
3. Increase in frequency and intensity of extreme events (especially drought and high temperature) that would adversely impact agronomic production and
4. Increase in risks of soil degradation and desertification (Lal and Stewart 2010a).

The production of fruits and vegetables in developing countries has considerably increased in recent years. However, an optimal use of these resources depends not only on the production increase in itself, but also on the improvement, in parallel, of associated infrastructure and postharvest operations of the produce, before it reaches the final consumer. Value-adding technological and socio-economic aspects, such as employment generation and quality and safety of the final product, are critical for the efficient performance of the fruit and vegetable system. Since trade in fruits and vegetables has reached record levels in both developed and developing countries for socio-economic, nutritional and cultural reasons among others, technological alternatives to facilitate and stimulate the development of the marketing of fruits and vegetables are required. This Manual for the preparation and sale of fruits and vegetables presents and clearly explains the main aspects to be taken into account when undertaking a commercial activity involving fruits and vegetables (FAO 2004).

Food security is critical to human health. Food security is achieved when all people have constant access to adequate, safe, and nutritious food that is economically accessible, socially acceptable, and allows for an active and healthy life. The world's population continues to grow rapidly but large areas of cropland have to be abandoned every year due to soil degradation. This combination has lead to a worldwide decrease in per capita cereal production since the 1980s. The trends of lost croplands and decreased per capita production will need to be stopped or reversed if we are to meet increasing food needs in the future. Building and maintaining soil health will also be critical in the supply of safe and nutritious food for future populations. Most people recognize that soil plays a significant role in food production, but fewer are aware of the role of soils in food security from a health perspective. Many of the elements that are required for human health come from the soil through either plant or animal products consumed by humans. Some essential elements may also be acquired directly through the voluntary and/or involuntary consumption of soil. There are also a number of ways that soils can have a detrimental affect on human health. Heavy metals in soil can be taken up by plants and passed on to those who consume them. Ingestion or inhalation of soil particles can expose humans to heavy metals, organic chemicals, and pathogens, and airborne dust can cause direct health problems through irritation of the respiratory passages. Despite the obvious connections between soils and human health, there has not been a great amount of research done in this area when compared to many other fields of scientific and medical study. More research in this area is essential to protect and enhance human health (Brevik 2009).

The concept of *food security* has been undergoing refinement during the last 50 years. Immediately after World War II, food security meant building emergency grain reserves and ensuring the physical availability of food in the market. After the onset of the green revolution in the late 1960s, it became obvious that economic access to food is equally important for ensuring food security at the household level. During the 1980s, it became evident that the gender dimension of food security should receive attention, in view of the growing feminization of poverty and agriculture. This was highlighted at the World Conference on Women held at Beijing in 1995. The principle of social access, with reference to women and marginalized communities was hence added to the concept of food security. Finally, after the UN Conference on Environment and Development held at Rio-de-Janeiro in 1992, there has been an increasing understanding of the role of environmental factors in food security. The ecological foundations essential for sustained agricultural progress are increasingly under stress due to human activities. Agenda 21 of UNCED addresses these concerns. Without safe drinking water and environmental hygiene, the biological absorption and retention of food will be poor. Thus, environmental access to food becomes important (Swaminathan 2004).

The concept of food security has several facts. These include an appropriate volume of stable food supplies, access to available supplies, food safety, nutritional balance, and social or cultural food preference. This concept of food security has developed over several decades, starting in the 1970s and being constantly and steadily refined through the 2000s. By 2001, the **FAO definition of food security** had been refined to: *"Food security [is] a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life"*. Basically, food security is seen as being achieved when all people have physical, social, and economic access to adequate, nutritious, and safe food that meets their dietary needs and their food preferences, allowing for an active and healthy lifestyle. This means the concept of human health is intricately linked to the concept of food security and, therefore, soil properties and processes that influence the quantity and quality of food will also be viewed as influencing human health (Brevik 2009).

Food security is defined as the access at any time to sufficient food to maintain a healthy, active life. ***Access*** is a key term here: people may access food by buying it or by producing it themselves. The household is the unit where people ensure food security; it includes productive individuals as well as dependent children and aged or sick persons. In a household, some persons will eat more than others, according to rank, body weight, and activity; household nutrition is deemed adequate, for statistical purposes, when the household ensures to its members an average 2200 cal per person per day. At the level of a country, because affluent households will consume much more food than poor households, the threshold for national food security is set at 2,700 cal per person per day. National food calories supply – dietary energy supply (DES) – can be determined on the basis of statistics on domestic agricultural production and on food trade. Countries with a DES above 2,700 are likely to contain only few food-insecure people and this figure is often set as a target in economic policy. In rich countries, where the food bill is a minor part of household expenditure, the DES tends to meet a ceiling around 3,500. People simply cannot ingest more calories without jeopardizing their health and life expectancy (Klohn 2004).

Recently, FAO announced that world hunger is projected to reach a historic high in 2009, indicating that food insecurity remains a global issue. While it has been suggested that both bio-energy production and the global economic crisis have contributed to the current food insecurity situation, food insecurity is likely to increase under climate change, unless early warning systems and development programs are used more effectively (Brown and Funk 2008). Although the FAO definition of security also includes food quality, insufficiency of micronutrients essential for human development and health attracts less attention, albeit that it has been an issue affecting a large percentage of the global population (Welch and Graham 2004).

Therefore, it is clear that micronutrient deficiency and/or the toxicant accumulation are further hampering food security in different parts of the world. Hence, it could be concluded that ensuring food security is a multi-faceted goal, and requires holistic approaches towards harmonization among land use, environmental sustainability, economic benefits and human health. Although technological advancements, such as irrigation and new improved cultivars, can enhance food security, soil as the fundamental resource remains the core of the issue. Soil quality (and hence nutrients) can play a significant role in alleviating the negative impacts from other societal problems. There are roughly four aspects of soil quality that have often been discussed in relation to food security in the literature; these include soil erosion, soil biological properties, nutrient balance and soil pollution (Zhu 2009).

Food insecurity exists when people lack access to sufficient amounts of safe and nutritious food, and therefore are not consuming enough for an active and healthy life. This may be due to the unavailability of food, inadequate purchasing power, or inappropriate utilization at household level (FAO 2012a).

Most food produced worldwide depends on agriculture; "wild" ecosystems could produce not more than food for 10 % of the global population. A main input to agricultural production is water, either in the form of rainfall or of irrigation water applied to crops. However, a large number of people (13 % of global population, about 800 million) do not have access to sufficient and adequate food for their nutritional requirements. In particular, the impact of food insecurity on children, in terms of stunted bodies, minds and hopes, is devastating. The cause of food insecurity is poverty, an expression of lack of monetary income, social protection networks, or access to the land and water necessary for self-sustenance. A majority of poor and food-insecure people are rural people who can hardly get jobs in the industry and services sectors. Overall agricultural production constraints, including water scarcity, are not as yet a cause of food insecurity: more food could be produced on the globe if the poor could exercise demand for it. Various national policy measures addressing removal of the causes of poverty can contribute to improvement of the food security of disadvantaged groups. Such policies need to be pro-poor and redress existing entrenched inequity in terms of trade, government-provided services and gender. Man-made agricultural systems claim sizeable amounts of water and other environmental resources and much larger efforts by society will be required to ensure that agriculture finds a sustainable place in the environment in which it is embedded (Klohn 2004).

The world population is increasing at a rate of six million/month, adding that of the U.K.'s population every year, and projected to reach eight billion by 2030. By 2010, there are more than three billion people living in the tropics and subtropics. Most of them are surviving on <$ 2 per day, and are strongly impacted by degradation of soil quality and its alterations by natural and anthropogenic factors. Consequently, food demand will increase by 50 %, water demand by 30 %, and energy demand by 50 %. The number of food-insecure people (millions) in the world was 917 in 1970, 904 in 1980, 839 in 1990, 854 in 2007, and was projected to decrease to 680 by 2010. In contrast, the number of food-insecure people increased to 954 million in 2008 and 1,017 million in 2009 because of increase in food prices and severe drought in some regions. Furthermore, it is widely recognized that the U.N. Millennium Development Goals of reducing hunger by 50 % by 2015 will not be met. The problem of food insecurity is especially severe in the South Asia/Pacific region and in Sub-Saharan Africa. The widespread problem of soil degradation and desertification, persistent use of extractive farming practices, non-adoption of recommended soil agronomic practices, and little attempt to restore degraded soils through investments in use of essential inputs e.g., soil amendments, irrigation are among principal causes of low agronomic yield and increasing food gap in Sub-Saharan Africa, South Asia and elsewhere. There is also a decrease in the per capita availability of arable land and of fresh water supply for agriculture. The per capita arable land area worldwide was 0.40 ha in 1961, 0.25 ha in 2000, and will decrease to <0.1 ha in many densely populated countries. By 2025, the per capita arable land area will be 0.03 ha in Egypt, 0.05 ha in Bangladesh, 0.06 ha in China, 0.07 ha in Pakistan and 0.11 ha in Ethiopia. The serious problem of malnourishment is exacerbated by the deficiency of micronutrients in food grown on degraded/depleted soils. Deficiency of micronutrients in diet is an important cause of morbidity and mortality among children. Health-related problems are especially severe because of an acute deficiency of Zn, Fe, Se, B, I, etc. More serious than land scarcity, the shortage of renewable fresh water resources will be a major constraint even in the near future. Among 30 densely populated countries, which will face severe water shortages by 2025, are India, China, Egypt, Iran, and Nigeria (Lal and Stewart 2010a).

Therefore, it could be concluded that food security implies physical, social, and economic access to sufficient, safe, and nutritious food by all people at all times to meet their dietary and food preferences for an active and healthy life. Whereas, food insecurity exists when people lack access to sufficient amounts of safe and nutritious food, and therefore are not consuming enough for an active and healthy life. This may be due to the unavailability of food, inadequate purchasing power, or inappropriate utilization at household level.

2.8 Rural Poverty, Water and Food Security

As mentioned before, it is known worldwide that water is an especially important natural element because of its interactions with life-related issues, since it is needed to support life. Energy, food, and the environment in general are inseparably related to its presence and quality. Ironically, water is the first natural resource to be affected by poor practice in the production of either energy or food. Water is an "environment" itself, being the support milieu for many ecosystems. As a resource, it is one of the most fragile and sensitive of all to pollution and contamination.

Because of the uneven distribution of water resources, water scarcity may be acutely felt in some parts of the world and not in others, where it is abundant. Water scarcity problems are always local, arising at "*dry spots*" and spreading from there into regions and entire river basins. Trade, however, has a growing role in ensuring food security, moving food to countries and regions where there are temporary or chronic deficits. An individual requires some 40 m^3 per year of safe, clean domestic water for food preparation, personal and domestic hygiene, and some green surroundings although hardy people, dismissing water-related comfort, can survive on 4 m^3 per year. If there are so many people that lack clean domestic water supply, this is not because the modest amount required is not available, but rather because billions of people cannot pay the cost of capturing, conditioning, and distributing it. As for food, we have seen that producing the annual food requirements for one person requires not less than 550 m^3 per year. In our diverse world, wherever there is good rainfall, food will be produced through rain-fed agriculture that does not raise too much competition to domestic water supply. However, people living in a rainless desert, to grow their basic food crops locally would need the full amount of 550 m^3 of water per person per year to be available for irrigation, with a sizeable increase to cater for the high evaporation losses in an arid climate. Domestic water requirements are in additions to this amount. No wonder that since early times people in arid regions have turned to trading for their food security (Klohn 2004).

"***Virtual water***," a term coined in the 1990s, refers to *the amount of water that would be needed to replace food imports by locally produced food, supposed to ensure national food security*. Local food autonomy carries a meaning in a strategic context, as locally produced food provides resilience against blockades and embargoes – those ages-old tools to submit people of other persuasion into obedience. Dismissing strategic concerns, however, the economics of importing 1,000 m^3 of water to produce 1 t of cereal instead of importing the cereal right away is, at first sight, questionable: funds are scarce and better investment opportunities are undoubtedly available. Trading of food contributes greatly to food security by making it available locally at the globally most attractive prices – plus freight and insurance. Trade, however, can only contribute to food security if the people needing to procure food have some goods or services to provide in payment – in short, money. People who are hard pressed to eat every day are not much of a market for anything but food, and there are few legitimate things that the non-poor wish to acquire from the poor (Klohn 2004).

Food security is often linked with national security, as a society that fails to provide access to food to its members is at risk of collapse. Countries dependent on irrigation for domestic food production often argue that water security is a part of national security. When irrigation depends on rivers or aquifers flowing through more than one country, this position makes water-sharing negotiations fraught with difficulty for policy makers. International conflict with its related military expenditure and stifling effect on trade is a poor choice, given that both water and basic food, while indispensable, are not expensive. Facing the domestic conflict of reallocating water to high-value uses can be a unviable alternative for the political establishment. Rural poverty is caused by unequal land distribution, direct and indirect taxation of agriculture and trade, and agricultural policies and services biased in favor of large-scale farming. On a global average, three out of four poor people are rural, but the balance is shifting given rural-urban migration, with an increasing proportion of women left behind in rural areas as the poorest of the poor. An adequate mix of policies to ensure food security in these situations may be quite difficult to define and tradeoffs are unavoidable. For example, to boost domestic food production and lift the income level of rural people, domestic food prices should be remunerative to farmers and induce them to produce. However, the food basket of the urban poor must be filled at the lowest possible price, and this could be achieved through cheap food imports. In many developing countries with a majority of the poor rural, urban bias and reliance on food imports has meant that farmers have not been encouraged to produce or invest, leading to stagnation (Klohn 2004).

Water user associations, where rules for water use are established and decisions on water distribution and system maintenance are taken, are a key to the success of irrigation as a tool for rural development and poverty alleviation. The poorest people, landless farmers and women, have been consistently marginalized in these associations; when this happens, they cannot influence water management decisions. Non-agricultural uses of irrigation water for drinking, washing, cooking, cleaning, and for livestock, were for a long time neglected because male-led user associations have tended to consider these socially beneficial uses, which are usually in the domain of women, as a low priority or even illegal. Similarly, women are often denied water rights and excluded from male-dominated networks in which major decisions on rules, implementation, and sanctions on water rights are taken. The exclusion of women is based on arguments such as their supposed inability or unsuitability to carry out maintenance work and other obligations, that they are not heads of households, or that they do not own land. For equity and poverty alleviation, it is almost essential that women and men are given equal obligations and rights. Water users associations' membership should recognize women's work in field irrigation instead of their position in the household (Klohn 2004).

Therefore, it could be summarized that rural poverty is caused by unequal land distribution, direct and indirect taxation of agriculture and trade, and agricultural policies and services biased in favor of large-scale farming. On a global average, three out of four poor people are rural, but the balance is shifting given rural-urban migration, with an increasing proportion of women left behind in rural areas as the poorest of the poor.

2.9 Soil Science and the Understanding of Food Security

Soil is a basic natural resource for food production, the vast majority of food we consume is either directly or indirectly derived from soil. Soil quality determines the quantity (calories) and quality (nutritional value and safety) of the foods grown. Protecting the soil's physical, chemical and biological integrity is therefore of vital importance in safeguarding global food security. Soil science, as a discipline, will contribute to new knowledge related to soil quality and its sustainable management. However, soil scientists are not alone in securing the global food production system, instead they shall work with environmental engineers, agronomists, nutritionists, animal scientists and social scientists in developing integrative approaches to soil conservation, material cycling and environmental protection. The preeminence of soil as the basic natural resource for food production makes soil science an indispensable discipline in safeguarding global food security. Endeavors in developing new knowledge and soil science-based best farming practices (BFPs) will enhance our ability to support food security globally, these endeavors include:

- The development of rapid and reliable monitoring tools for soil and food quality and digital archiving of the monitoring data to assist decision making;
- The development of new soil conservation systems to minimize soil erosion and to protect soil biodiversity;
- Working with environmental engineers to develop sustainable ways of recycling nutrients from wastes;
- The development of integrative and cost-effective ways of enhancing trace elements while minimizing the accumulation of toxic substances in food, through crop breeding, the application of novel fertilizers as well as novel pollution prevention and remediation technologies (Figs. 10 and 11; Zhu 2009).

Soil quality strongly impacts agronomic productivity, use efficiency of input, and global food security. The significance of dependence of food security on soil quality is likely to increase with decrease in per capita land area, increase in extent and severity of soil degradation, and the projected global warming. Eating food is an agricultural act, and soil is the foundation on which agriculture is practiced. Because humans will always depend on food, management of soils and agriculture must be

Fig. 10 The decrease of soil salinity level because of the continuous cultivation of soil (about 6 years old) helped to cultivate new and more sensitive crops to soil salinity in Nubaria district, Egypt. The good understanding of soil science is very important for food security (Photo by H. El-Ramady)

Fig. 11 Good sustainable soil quality management may be useful to cultivate okra crop in Shalateen district, Egypt. Organic farming for okra during December enhanced the early harvesting (Photo by H. El-Ramady)

integral to any initiative toward advancing food security. While money can be created by a speculative bubble, at least temporarily until it bursts as was the case with the global financial crisis experienced in 2007–2008, food has to be grown/produced through judicious management of soil and water resources. For land managers and agricultural scientists to succeed in the war against hunger, degraded and desertified ecosystems must be restored, salinized land must be reclaimed, depleted and impoverished soils must be improved, and those devoid of fauna and flora must be rehabilitated. We can no longer take the soils for granted (Lal and Stewart 2010b).

Soil loss due to erosion is a major threat to food security. Human-induced soil erosion has been known for a long time. Soil erosion often removes the finer and more fertile fraction of the soil, and it is clearly a big threat to sustainable agricultural production, thus to food security. Many experimental studies have explicitly demonstrated that for most tropical and cumulative soil loss is a curvilinear and negative exponential one (Stocking 2003). At the technological level, developing best farming practices (BFP) seems the key to curbing soil erosion, as BFP will integrate many appropriate technologies available under different socio-economic conditions. However, it should be noted that both the development and adoption of BFP require substantial economic investment and governance at all levels (Zhu 2009).

The importance of maintaining soil's biological properties for food security has also attracted wide attention in recent years. Soil is perhaps the most remarkable habitat on Earth that is harboring rich biodiversity. Soil biota is responsible for the turnover of organic matter and the transformation of nutrients, such as N and S, thus is an integral part of soil quality. The role of soil biota in plant growth and hence productivity is now well known (Wardle et al. 2004). An example of the role of soil biota in ensuring food security is biological nitrogen fixation. It has been recently estimated that 50–70 Tg N may be fixed annually by biological agents in the global agricultural system (Herridge et al. 2008). Despite the extremely high diversity of the soil microbial community, more recently it has been shown experimentally that soil microbial communities of differing composition are functionally dissimilar, thus managing soil biodiversity seems even more important than previously perceived (Zhu 2009).

We are what we eat. Since what we eat is ultimately derived from soil, our health is heavily influenced by the soil's chemical compositions, particularly trace elements, such as iodine, selenium, zinc and iron. It is well known that iodine deficiency can cause goiter formulation; the first endemic disease attributed to the environment (Oliver 1997). One typical example is found in Xinjiang, the most distant city from the sea on Earth, where iodine deficiency is still a problem. An example is selenium deficiency and the prevalence of Keshin-Beck Disease in certain areas of China. Today, because of the great mobility of people and trading of food between regions/countries, the problem of diseases related to the environment seems less important, and tends to be neglected. However, firstly, one should note that the deficiency of trace elements can occur well before the development of illness and other visible symptoms; secondly, poverty stricken population often have less mobility and are largely reliant on what they can grow locally. Since in most cases, dietary intake is the predominant source of trace elements ingestion in humans, it is important that trace elements in the food supply chain are characterized. We have recently characterized the selenium situation in the global rice supply chain, and we believe that this should be expanded to other elements and other food sources (Williams et al. 2009). In ancient China, people learnt to use seaweed to cure goiter (Oliver 1997), and in modern society fortified salt or other functional food are widely available to compliment of the deficiency of trace elements in food. However, for a better delivery mechanism, it has been argued that biofortification (i.e., improving trace element density in primary food sources, such as in cereals) is more widely accessible and more cost-effective. In parallel to trace element deficiency, excessive concentrations of toxic elements in food are confounding the nutritional value of the food and causing health problems. One example would be cadmium contamination in rice and “itai-itai” disease. With rapid industrialization, there seems no end to toxic substances entering the environment, and efforts should be made to ensure that the entry of these toxic substances into our food supply chain is minimized (Zhu 2009).

Humanity is at the crossroads as far as the global issues of food insecurity, climate disruption, and soil and environmental degradation are concerned. The strategy is to learn and change – alter land use and soil management to restore degraded soils and desertified ecosystems to a desirable stability/quality domain. The two key questions are: (1) How can we implement ways to expand human opportunity and facilitate human learning to sustain soil/ecosystem resilience? (2) How can we develop and implement soil/ecosystem/social resilience, integrated understanding, policies, and action among scientists, economic and public interest groups, and farmers and land managers so that knowledge and science-based action plan is evolved and implemented? The strategy is of moving toward sustainable soil quality and agricultural improvement through research-based policies. Sustainable soil quality management approaches are those which permanently retain the ability of soils to provide ecosystem services and recover after an anthropogenic perturbation. These approaches involve weighing up of options, keeping options open, and creating new opportunities when old options are no longer feasible or become redundant (Lal and Stewart 2010b).

Therefore, it could be concluded that soil is a basic natural resource for food production, the vast majority of food we consume is either directly or indirectly derived from soil. Soil loss due to erosion is a major threat to food security. Human-induced soil erosion has been known for a long time. Protecting the soil’s physical, chemical and biological integrity is therefore of vital importance in safeguarding global food security.

2.10 Managing Soil to Address Food Security and Environmental Issues

In view of the increasing demand for food production and improvements in its nutritional quality, there is a need for change in the context of agricultural science

Table 7 Global soil resources and their characteristics in relation to food security

Soil resource	Action plan
Soil resources are unequally distributed among biomes and geographic regions	Choose land use and farming system on the basis of climatic, physiographic and hydrologic parameters
Most soils are prone to degradation by land misuse and soil mismanagement	Select cropping systems, tillage methods, water conservation and nutrient management options on the basis of soil quality and desired output
Soil erosion and erosion-induced degradation depend on "how" rather than "what" crops are grown	Adopt CA, mulch farming, cover cropping, contour hedges of perennials, and controlled grazing considering low tolerable level (<1 t ha^{-1} year^{-1}) of erosion for soils of the tropics
Susceptibility to soil degradation increases with increase in mean annual temperature and decrease in precipitation	Identify management systems with cow cropping and grazing intensity, and based on water harvesting, ground water recharge and multiple use of scarce eater resources
Processes of soil degradation operate at a faster rate than those of restoration	Identify key soil properties and processes and understand their critical/threshold levels to avoid irreversible soil degradation
Soil resilience depends on inherent physical, chemical and biological properties and processes	Identify land use and soil management practices that will maintain and enhance soil's ability to recover from anthropogenic and natural perturbations (e.g., positive C and elemental/nutrient balance)
Soils are a non-renewable resource over the human time scale	Choose preventative measures for erosion, salinization and SOC depletion over restorative inputs and rehabilitational techniques
Optimal levels of soil physical properties and processes are important to effectiveness of chemical and biological properties and processes	Improve soil structure and optimize soil temperature and moisture regimes to enhance use efficiency of fertilizers and realize the benefits of BNF, mycorrhizal inoculation and yield potential of GM crops
Soil structure depends on volume, stability, and continuity of retention and transmission pores	Promote activity of earth worms, include cover crops with a deep tap root system, and use compost and organic amendments
Soil productivity is constrained by the weakest parameter/link (e.g., PAW, micronutrients, SOC concentration, rooting depth) micronutrient-dense varieties	Use INM to replace macroelements, and micronutrients harvested in crops and animal products, and adopt

Adapted from Lal (2008a, b)

(Evans 2005). It is equally important to understand how sustainable agriculture can address both the environmental concerns and human health issues, diffuse and minimize pollution from agricultural practices (Burkart 2007), predict changes in crop productivity over time (Ewert et al. 2005) and adapt to ecological systems (Giloli and Baumgärtner 2007) of changing societal needs. Sustainable and efficient practices must address global environmental impacts (Thajun and Van Ranst 2005). There is a need for a paradigm shift in land husbandry (Gowing and Palmer 2008), and principles and practices of soil management. Principles (Table 7) and

Table 8 Principles and practices of maintaining healthy soils for healthy life

Principles	Practices/strategies
The biophysical processes of soil degradation are driven by social, economic and political forces	Involve farmers, land managers and policy makers in the decision making process of restoring degraded soils
When people are poverty stricken, desperate and hungry, they pass on their suffering to the soil	Meet the basic necessities (food, feed, fuel) before emphasizing the need to improve the environment and stewardship of land
Marginal soils, cultivated with marginal inputs produce marginal yields and support marginal and unhealthy living	Cultivate the best soils by best management practices to produce the best yields to support a healthy living while saving the land for nature conservancy
It is not possible to take more out of a soil than what is put in it without degrading its quality	Maintain a positive/favorable C and plant nutrient budgets in soils for the desired level of agronomic production
Plants cannot differentiate the nutrients supplied through organic manures or inorganic fertilizers, as long as all essential nutrients are available at the critical stages of growth and in the quantities required	Adopt INM strategy involving nutrient recycling, BNF, mycorrhizal inoculations, GM varieties, and judicious use of chemical fertilizers to supply macronutrients and microelements using nanoenhanced materials and slow-release formulations
Even the elite varieties cannot extract water and nutrients from any soil where they do not exist	Integrate genetics and soil management options to achieve the desired impacts on food security
Soils are in part the cause and also the victims of the global warming	Restore degraded soils and improve SOC pools to off-set industrial CO_2 emissions through terrestrial C sequestration with a potential of ~3 Pg C $year^{-1}$
Improving soil quality is essential to sustainable development	Make soil management and agricultural improvements as the engine of economic development is SA, SSA, and elsewhere
Traditional systems by themselves are not adequate to meet the growing demands of increasing population with rising aspirations	Build upon the traditional knowledge and use modern innovations of nutrient management, water productivity improvement, disease suppressive soils, nanoenhanced materials and deliverance systems, satellite imagery, and remote sensing technologies, and precision farming
There is a strong historic link between soil degradation and the extinction of numerous ancient civilizations (e.g., Mayans, Incas, Mesopotamians, Indus)	Never ever take soils for granted

Adapted from Lal (2009b)

sustainable practices (Table 8) of soil management must be fine-tuned to site-specific needs and the growing aspirations of rapidly increasing populations in developing countries (Lal 2009a).

Ecologically restored and judiciously managed, global soil resources are adequate to meet the essential needs of the present and future populations. Soil scientists, in cooperation with agronomists and crop breeders, have the technology to feed a population of ten billion (Lal 2006). Integrating genetics and soil management options is essential to achieving great impact of agricultural technology on food production in harsh environments (Twomlow et al. 2008).

The adoption of this technology, however, depends on the infrastructure, support services and political will. Innovative technologies also exist to bring about a quantum jump in food production, especially in Sub-Saharan Africa (SSA) and South Asia (SA) (NRC 2008). These technologies include the following:

1. Assessing by remote sensing critical plant nutritional stresses for managing soil quality by using the Normalized Difference Vegetation Index or NDVI (Raun et al. 2001).
2. Using zerolites and nano-enhanced materials to enhance use efficiency of fertilizers and improve plant-available water capacity of the soil (Kijne 2001, 2004), increase the availability of micronutrients e.g., Zn (Oren and Kaya 2006), and improve the quality of irrigation water through wastewater treatment (Daubert et al. 2003).
3. Inoculating soils with endophytic bacteria that can increase BNF capacity and improve soil fertility (Lodewykx et al. 2002).
4. Using microbial processes to increase P uptake (Jackobsen et al. 2005), and improve drought tolerance in plants (Marulanda et al. 2007) and increase tolerance to salinity or irrigation with saline water.
5. Conserving water in the root zone and enhancing the efficiency of its use through improving soil structure and quality by using organic amendments, NT and CA (Rockström et al. 2007), and using drip irrigation and drip sub-irrigation for decreasing losses and increasing plant uptake (Lal 2009a).

Therefore, it could be concluded that it is equally important to understand how sustainable agriculture can address both the environmental concerns and human health issues, diffuse and minimize pollution from agricultural practices, predict changes in crop productivity over time and adapt to ecological systems of changing societal needs. Hence, sustainable and efficient practices must address global environmental impacts.

2.11 Opportunities for Advancing Food Security Through Soil Management

Globally, the implementation of Green Revolution technology increased average cereal yield from 1.2 t ha^{-1} in 1951 to 3.4 t ha^{-1} in 2008 (Ingram et al. 2008). In Europe, grain yields also increased linearly between 1960 and 2005 (Ewert et al. 2005). Despite impressive gains in crop yields and total food grain production in SA and elsewhere around the world during the second half of the twenty-first century, the Green Revolution by-passed SSA. Crop yields in SSA have stagnated at about 1 t ha^{-1} for cereals e.g., sorghum, millet, maize, 3–5 t ha^{-1} for roots and tubers e.g., cassava, sweet potato and yam and 100–200 kg ha^{-1} for legumes e.g., cowpeas,

Table 9 Components of sustainable soil management system for advancing food security in the tropics

Farming operation/objectives	Recommended management practices
1. Seed bed preparation	No-till farming, crop residue mulch
2. Rotations	Legume-based crop rotations, agroforestry
3. Water management	Mulch farming, water harvesting and recycling, efficient irrigation methods
4. Fertility management	Manuring, BNF, biochar, slow release formulations of fertilizers, nano-enhanced
5. Erosion control	No-till, agroforestry, cover cropping, conditioners
6. Soil biotic activity	No-till, manuring, mulch farming
7. Enhancing SOM pool	Complex crop rotations, no-till, agroforestry, biochar application, manuring and biosolids

Adapted from Lal (2009d)

because of soil degradation caused by erosion, nutrient mining, and depletion of the soil organic carbon (SOC) pool. Adoption of proven soil management technologies has a potential to quadruple production of food crop staples in SSA and also improve their nutritional quality. Globally, adoption of recommended management practices (RMPs) could enhance average cereal grain yields from 3.4 t ha^{-1} in 2008 to 4.2 t ha^{-1} in 2020 (Ingram et al. 2008).

Yet application of the Green Revolution technologies has been a debatable issue for both biophysical and social reasons. Environmental consequences of agricultural intensification in India and China must be addressed. Furthermore, the problem is not with the Green Revolution technology. Rather, it is its misuse and mismanagement, which have created the environmental problems. It is over fertilization, overuse of pesticides, over simplification of crop rotations, excessive application of flood-based irrigation, unnecessary plowing, complete removal of crop residues, and uncontrolled communal grazing which have exacerbated soil and environmental depredation. This problem lies in using "technology without wisdom" (Table 9; Lal 2007b).

Therefore, it could be summarized that globally, adoption of recommended soil management practices could be addressed and adoption of proven soil management technologies has a potential to quadruple production of food crop staples and also improve their nutritional quality.

3 Plant Nutrition and Human Health

Health was defined as "*a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*" by the World Health Assembly in 1948. Note that this definition includes three primary aspects of health: (i) physical, (ii) mental, and (iii) social. Physical fitness is achieved through proper nutrition in the daily diet and regular exercise. Mental fitness is achieved through emotional and psychological well-being and is also partially dependent on proper nutrition, and social fitness is achieved through the ability to operate comfortably within the expectations of the society the individual lives in. These components of health can also be seen within the food security definition of the FAO, again demonstrating the interrelationship between food security and human health (Brevik 2009).

3.1 Undernourishment or Chronic Hunger, Malnutrition and Under-Nutrition

Undernourishment or chronic hunger is the status of persons, whose food intake regularly provides less than their minimum energy requirements. The average minimum energy requirement per person is about 1,800 kcal per day. The exact requirement is determined by a person's age, body size, activity level and physiological conditions such as illness, infection, pregnancy and lactation. *Malnutrition* is a broad term for a range of conditions that hinder good health, caused by inadequate or unbalanced food intake or from poor absorption of food consumed. It refers to both undernutrition (food deprivation) and overnutrition (excessive food intake in relation to energy requirements). There are two basic types of malnutrition. The first and most important is protein-energy malnutrition--the lack of enough protein (from meat and other sources) and food that provides energy (measured in calories) which all of the basic food groups provide. This is the type of malnutrition that is referred to when world hunger is discussed. The second type of malnutrition, also very important, is micronutrient (vitamin and mineral) deficiency. This is not the type of malnutrition that is referred to when world hunger is discussed, though it is certainly very important (FAO 2012b).

Fruits, nuts, and vegetables play a significant role in human nutrition, especially as sources of vitamins [C (ascorbic acid), A, thiamine (B_1), niacin (B_3), pyridoxine (B_6), folacin (also known as folic acid or folate) (B_9), E], minerals, and dietary fiber. Their contribution as a group is estimated at 91 % of vitamin C, 48 % of vitamin A, 30 % of folacin, 27 % of vitamin B_6, 17 % of thiamine, and 15 % of niacin in the U.S. diet. Fruits and vegetables also supply 16 % of magnesium, 19 % of iron, and 9 % of the calories. Legume vegetables, potatoes, and tree nuts (such as almond, filbert, pecan, pistachio, and walnut) contribute about 5 % of the per capita availability of proteins in the U.S. diet, and their proteins are of high quality as to their content of essential amino acids. Nuts are a good source of essential fatty acids, fiber, vitamin E, and minerals. Other important nutrients supplied by fruits and vegetables include riboflavin (B_2), zinc, calcium, potassium, and phosphorus. Fruits and vegetables remain an important source of nutrients in many parts of the world, and offer advantages over dietary supplements because of low cost and wide availability (Tables 10 and 11; Kader et al. 2004).

Undernutrition is the result of prolonged low levels of food intake and/or low absorption of food consumed. Generally applied to energy (or protein and energy) deficiency, but it may also relate to vitamin and mineral deficiencies. Why are no hunger statistics published for 2011? During its meeting in 2010, the Committee on

Table 10 Nutritive constituents of fruits and vegetables that have a positive impact on human health and their sources

Constituent	Sources	Established or proposed effects on human-wellness
Vitamin C (ascorbic acid)	Broccoli, cabbage, cantaloupe, citrus fruits, guava, kiwifruit, leafy greens, pepper, pineapple, potato, strawberry, tomato, watermelon	Prevents scurvy, aids wound healing, healthy immune-system, cardiovascular-disease
Vitamin A (carotenoids)	Dark-green vegetables (such as collards, spinach, and turnip greens), orange vegetables (such as carrots, pumpkin, and sweet potato), orange-flesh fruits (such as apricot, cantaloupe, mango, nectarine, orange, papaya, peach, persimmon, and pineapple), tomato	Night blindness prevention, chronic fatigue, psoriasis, heart disease, stroke, cataracts
Vitamin K	Nuts, lentils, green onions, crucifers (cabbage, broccoli, Brussel sprouts), leafy greens	Synthesis of pro-coagulant factors, osteoporosis
Vitamin E (tocopherols)	Nuts (such as almonds, cashew nuts, filberts, macadamias, pecans, pistachios, peanuts, and walnuts), corn, dry beans, lentils and chickpeas, dark-green leafy vegetables	Heart-disease, LDL-oxidation, immune-system, diabetes, cancer
Fiber	Most fresh fruits and vegetables, nuts, cooked dry beans and peas	Diabetes, heart disease
Folate (folicin or folic acid)	Dark-green leafy vegetables (such as spinach, mustard greens, butterhead lettuce, broccoli, brussels sprouts, and okra), legumes (cooked dry beans, lentils, chickpeas and green peas), asparagus	Birth defects, cancer, heart disease, nervous system
Calcium	Cooked vegetables (such as beans, greens, okra and tomatoes) peas, papaya, raisins, orange, almonds, snap beans, pumpkin, cauliflower, rutabaga	Osteoporosis, muscular/skeletal, teeth, blood pressure
Magnesium	Spinach, lentils, okra, potato, banana, nuts, corn, cashews	Osteoporosis, nervous system, teeth, immune system
Potassium	Baked potato or sweet potato, banana & plantain, cooked dry beans, cooked greens, dried fruits (such as apricots and prunes), winter (orange) squash, and cantaloupe	Hypertension (blood pressure) stroke, arteriosclerosis

Adapted from Kader et al. (2004)

World Food Security (CFS) asked FAO to review its methodology for estimating undernourishment in order to provide more timely updates and incorporate all relevant information, including analysis of the large number of household surveys that have become available in recent years. Therefore, no updated estimates for the number of undernourished people in 2009 and 2010 are reported, nor has an estimate been made for 2011 (FAO 2012b).

Table 11 Essential mineral nutrient elements besides N and S, daily requirements and the effects of deficiencies

Mineral nutrient	Daily adult requirements	Major deficiency symptoms in humans and domestic animals
Na + Cl	5 g	Dehydration (salt-loss syndrome), disturbance of kidney function (excess Na can aggravate hypertension)
P	1.5 g	Weakness of bones, skeleton deformities, rickets
K	2 g	Disturbances of growth and fertility, weakness of muscles, but K deficiency is rare
Ca	1 g	Bone stability reduced, neuromuscular disturbances
Mg	0.3 g	Cardiac insufficiency, grass tetany in cattle
Fe	10 mg	Anaemia (widespread, especially in women)
Zn	15 mg	Disturbances of body growth, healing of wounds, hair growth
Mn	3 mg	Disturbances of growth and fertility, skeletal deformities
Cu	2 mg	Anaemia, reduced fertility, damage to coronary blood vessels
I	0.2 mg	Disturbances of thyroid function (goiter problem)
F	2 mg	Caries (tooth decay)
Mo	0.1 mg	Dental caries
Se	0.05 mg	Necrosis of liver, eye damage
Co	–	Deficiency of vitamin B_{12}

Adapted from Roy et al. (2006)

Therefore, Fruits, nuts, and vegetables play a significant role in human nutrition, especially as sources of vitamins, folacin, minerals, and dietary fiber. Undernourishment or chronic hunger is the status of persons, whose food intake regularly provides less than their minimum energy requirements. Hence, Undernutrition is the result of prolonged low levels of food intake and/or low absorption of food consumed.

3.2 Soils and Human Health in a Historical Perspective

Although we still have much to learn about the exact connections between soils and human health, the idea that soils are important to human health is not necessarily a new one. As far back as approximately 1400 B.C. the Bible depicts Moses as understanding that fertile soil was essential to the well-being of his people. By the late 1700 and early 1800s, American farmers had recognized that soil properties had some connection to human health. In "Letters from an American Farmer", published in 1792, ***J. Hector St. John De Crvecoeur*** stated *"Men are like plants; the goodness and flavor of the fruit proceeds from the peculiar soil and exposition in which they grow"*. And in "Larding the Lean Earth", published in 2002, S. Stoll noted that North American farmers in the early 1800s recognized a link between an enduring agriculture and an enduring society, leading them to become concerned about the fertility of their soils and to seek ways of improving the soil in order to insure a healthy society. Continuing into the first half of the twentieth century, a 1940 publication by the International Harvester Company noted that poor soils lead to "stoop-shouldered, poverty-stricken people." Then, in 1947, ***Sir Albert Howard*** published his landmark work "*The Soil and Health: A Study of Organic Agriculture*", a work that took a critical look at modern production agriculture and at the link between soil fertility and health.

Despite these various lines of evidence of some earlier level of understanding that healthy soils are required for healthy people, the scientific study of the relationship between soils and human health is a fairly new undertaking. In his 1997 work "Soil and Human Health: A Review", M.A. **Oliver** states *"there is a dearth of quantitative information on the relations between elements in the soil and human health; there is much speculation and anecdotal evidence."* So, the scientific study of soils and human health is a recent undertaking, but the idea that healthy soils are required for healthy people is not a particularly new one (Brevik 2009).

It is well known that, the natural environment and its component including earth, air, water, plants, animals, etc., are considered as essential things for the preservation of health on this earth. For this reason, according to the Koran, the religious duties of man are not only to feed the poor but also to avoid polluting the environment. In other words, what is appreciable in the eyes of God is not only to be kind to human beings, but also to soil, air, water, plant, trees and animals, etc. These resources have a common characteristic, namely: they may be of continuous benefit to mankind if used wisely. In the light of the Holy Koran, the protection and maintaining of land and soil should be kept in mind (Deuraseh 2010). According to the Holy Koran: "*A sign for them is the earth (soil) that is dead. We revive it and We bring forth from it grain, so that they may eat thereof; and We have placed therein gardens of date-palm and grapes, and We have caused springs of water to gush forth therein, that they may eat of the fruit thereof, and their hands made it not. Will they not then give thanks?*" (Yasin 36: 33–35). Also, it is worth to mention that, the information revealed in the Koran 1,400 years ago confirms what modern science tells us-the fact that the same elements as these found in the soil are employed in the human creation, where: "*We created man from an extract of clay*" (Al-Mo'menon 23:12). The major components in clay minerals are typical the same in humans.

Therefore, it could be concluded that the relationship between soils and human health is established and frequented in the Bible, Koran and Torah. Also, there is a strong relation between production agriculture and its to the link between soil fertility and health.

3.3 Impacts of Soils on Human Nutrition

Fruit has been the inspiration of artists and its consumption has been associated with healthy dietary habits since ancient times. References to fruits such as grapes, pomegranates, dates and apples are frequent in the Bible, Koran and Torah. In many cases, these fruits are associated with eternal life as in ancient Egyptian and Sumerian cultures. Modern epidemiology shows that fruit and vegetable consumption reduces the risk of several chronic diseases, such as

Table 12 Nutritionally essential mineral elements in the human body

Element	Typical amount[a]
Ca	1,000 g
P	700 g
Mg	20–28 g
Na	1.3 g
K	110–150 g
Mg	20–28 g
Zn	2–2.5 g
Cu	120 mg
Se	20 mg

Adapted from Combs (2005)

[a] 70-kg reference

cardiovascular diseases and certain types of cancer (Hung et al. 2004). This has powered the interest of researchers in determining the biological activity of fruit and vegetable constituents. In addition to vitamins, minerals and dietary fiber, these foods provide a whole range of non-nutrient constituents that are considered biochemically to be secondary metabolites, and that have been suggested as being responsible, at least partly, for the health benefits associated with the regular consumption of fruit and vegetables. These secondary metabolites include different chemical families such as terpenoids (carotenoids, essential oils, steroids, etc.), nitrogen and sulfur-containing compounds i.e. glucosinolates of the *Brassicaceae* and sulphur compounds of the *Allicaceae* and phenolic compounds. This last group includes many different metabolites ranging from the very simple aromatic acids, such as *p*-hydroxy-benzoic acid, to complex oligomers and polymers as in the case of procyanidins, gallotannins and ellagitannins. Combinations with different sugars and aliphatic and aromatic acids, as well as glucuronides and sulphates are also common. The biological activity of these compounds is often related to their antioxidant capacity or their ability to neutralize free radicals that are the origin of many of the age-related diseases previously mentioned (Tomás-Barberán and Gil 2008).

Humans, like all living organisms, biosynthesize the proteins, nucleic acids, phospholipids, and many of the smaller molecules on which they depend for life functions. The health and well-being of organisms also depend on their ability to obtain from external chemical environments a number of compounds that they cannot synthesize, at least at rates sufficient to support those functions. Thus, of the large set of bioactive compounds and metabolites called “nutrients,” some are referred to as “essential” because they must be obtained from the air (oxygen), water, and diet. These include vitamins, some fatty acids, some amino acids, and several mineral elements. Foods contain essential nutrients as a result of the capacity of plants, and in some cases food animals, to synthesize and/or store them. The human body, therefore, consists of substantial amounts of “mineral elements” (Table 12) obtained mostly from such foods. These elements, of course, cannot be biosynthesized; ultimately, they are obtained from soils and, in turn, from the parent materials from which soils are derived. Nutritionally important mineral elements include some e.g., Mn that occur predominately in silicates, some e.g., Zn and Se that occur in silicates and sulfides, some e.g., copper Cu and Mo that occur in sulfides or as native elements with iron (Fe), and some e.g., Fe that occur in silicates, sulfides, and as the native metal. The most abundant of these is iron, which is the fourth most abundant element in the Earth's crust. About 22 mineral elements are known or suspected to be essential for humans and other animals. Some are required in fairly large amounts, grams per kilogram of diet, and are therefore referred to as "*macronutrients*"; others are required in much smaller amounts, e.g., microgram-to-milligrams per kilogram of diet and are referred to as "*micronutrients*." At least eight mineral elements function physiologically in their simple cationic forms (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Fe^{+2}, Cu^{+2}, Zn^{+2}, and Mn^{+2}) and can, therefore, be subject to chelation by either intact proteins or a variety of small, organic molecules. Some chelates e.g., the heme moiety in hemoglobin and myoglobin are essential in metabolism; some e.g., amino acids, EDTA facilitate the absorption, transport, and tissue storage of mineral ions; and others e.g., phytic acid, oxalic acid can interfere with the enteric absorption of certain essential cations. For example, the transition metal ions (Fe^{+2}, Cu^{+2}, and Zn^{+2}) form coordinate covalent bonds with ligands containing the electron-donor atoms N, S, and O, the histidinyl imidazole-N (Cu^{+2}), the cysteinyl sulfhydryl-S (Zn^{+2}), and the aspartyl and glutamyl carboxyl-O (Fe^{+2}, Cu^{+2} and Zn^{+2}). Three mineral elements function as anions or in anionic groupings i.e., Cl^{-}, PO_4^{-3} and MoO_4^{-2}. Two, iodine (I) and selenium, are nonmetals and function in covalent compounds e.g., iodothyronine, selenocysteine formed metabolically. The biological significance of these elements, therefore, tends to be a property of their particular organic species rather than of the element ones (Combs 2005).

Mineral elements are metabolized and, to varying degrees, stored by plants and animals, some of which constitute important sources of those elements in human diets (Table 13). That the mineral elements are not homogeneously distributed among various types of foods is clear: few foods other than dairy products are rich in calcium; sea foods constitute the best sources of iodine and chloride; meats are the most important sources of iron; and protein-rich foods comprise the best sources of Zn, Cu, and Se. Therefore, optimal mineral nutrition, like optimal nutrition in general, is most likely to be obtained from mixed diets based on a diverse selection of foods. Conversely, the monotonous, non-diverse, grain-based diets accessible to the poor of the developing world are likely to provide insufficient energy, protein, and minerals, especially Ca, Cu, Se, and biologically available Fe and Zn. At the same time, the increasing use in industrialized countries of non-diverse eating habits is associated with prevalent insufficient intake of such minerals as calcium (Combs 2005).

Soil can contribute to the total dietary intake of mineral elements. This can occur through adherent soil particles on foods and suspended soil particles in drinking and cooking water, as well as through the direct consumption of soil. The latter practice of soils can be deliberate in some communities in which the eating of clays occurs. Consumption of clays with high cation-exchange capacities can provide substantial supplements of Ca, Fe, Cu, Zn, and Mn; other clays can interfere with the enteric absorption of Fe and Zn. Consumption of iron-rich lateritic soils or waters draining them can provide enough iron to impair the utilization of Cu and Zn (Combs 2005).

Table 13 Some important plant and animal sources of essential mineral elements to human life

Element	Plant sources	Animal sources
Ca	Collards, mustard greens, broccoli	Dairy products, fortified juices, sardines, oysters, clams, canned salmon, Kale
P	Nuts, beans, peas, lentils, grains	Meats, fish, eggs, dairy products
Mg	Seeds, nuts, beans, peas, lentils, whole grains, dark green vegetables	
Na	Common table salt, seafood	Dairy products, meats, eggs
K	Fruits, dairy products, meats, cereals, vegetables, beans, peas, lentils	
Cl	Common table salt	Seafood, dairy products, meats, eggs
Fe		Meats (especially red meats), seafood
Cu	Beans, peas, lentils, whole grains, nuts, organ meats, peanut products, mushrooms	Seafood (e.g., oysters, crab), chocolate
Zn	Nuts, whole grains, beans, peas, lentils, fortified breakfast cereals	Meats, organ meats, shellfish
Se	Grain products, nuts, garlic, broccoli grown on high-Se soils	Meats from Se-fed livestock, sea fish
I	Iodized salt	Sea fish, kelp
Mn	Whole grains, beans, peas, lentils, nuts, tea	
Mo	Beans, peas, lentils, dark green leafy vegetables	Organ meats

Adapted from Combs (2005)

Therefore, it could be concluded that fruit has been the inspiration of artists and its consumption has been associated with healthy dietary habits since ancient times. References to fruits such as grapes, pomegranates, dates and apples are frequent in the Bible, Koran and Torah. In many cases, these fruits are associated with eternal life as in ancient Egyptian and Sumerian cultures.

3.4 Promotion of Human Health Through Soils

There are than 14 elements that are essential for plant growth that come from the soil, and many of these elements, such as calcium (Ca), iron (Fe), potassium (K), and others are also essential for human health. Essential soil elements that end up in the human diet are supplied through food from either plants that took the elements up from the soil during growth, or animal products after the animal obtained those essential elements from plants. Because plants depend on the soil for their nutritional needs, and all higher animals including humans depend directly or indirectly on plants for their nutrition, plants form the base of the food chain and, consequently, a major portion of the nutrients needed for human health originate with the soil. This section will take a closer look at the elemental content of the soil and at some of the ways soil nutrients are taken up and influence human health (Brevik 2009).

Irrigation and fertilization management, plant population, temperature, light quality and abiotic moderate stress can improve the antioxidant properties of fresh and processing fruits as many phytonutrients belong to the plant defence system. However, further research must be done to improve our knowledge of the effect of decreasing average temperature to save energy (greenhouse crops), increasing atmospheric CO_2 level, light quality and reflecting materials such as mulch, plant population and other agricultural techniques such as grafting and ion competition on the nutritional value of fruits. Interactions between genotype, ecophysiological factors and practical management have often not been considered. Additional whole plant, physiological, biochemical and cellular studies, integrated by modeling as biological systems, will constitute a useful framework for these research efforts (Dorais and Ehret 2008).

Increasing the amount of bioavailable micronutrients in fruits for human consumption is also a challenge that is particularly important for developing countries such as Fe, Zn and some industrialized countries i.e. Ca and can be achieved by soil and/or foliar applications, plant breeding and genetic engineering techniques, but also by increasing the concentration of compounds that promote micronutrient uptake such as ascorbic acid. Because of the high genetic variability concerning the Fe and Zn content of edible parts and the relatively simple genetics governing their accumulation, there would seem to be considerable potential for plant breeders to improve micronutrient quality of crops. As with any horticultural commodity, growers of berries, fruit crops and greenhouse crops such as tomato must employ agronomic practices which promote yield. In some cases, those conditions enhance nutritional quality, in some cases not. Moreover, growers must define their economic threshold, balancing the yield, taste and health quality of their product. This will be specific for each country and targeted market. However, based on the increasing consumer demand for tasty and healthy fruit, the value of growing crops which maximize human nutritional health factors will increase. Without doubt, the food production chain, from the seed to the consumer plate, will have to fulfill that demand (Dorais and Ehret, 2008).

There have been several attempts to examine the long-term outlook for the nutritional quality of fruits and vegetables, where smaller studies conducted during the last few decades have been collated and analyzed for trends (Davis et al. 2004). Although the authors of these metastudies concede that their methods are not perfect, there is reason to believe that the nutritional quality of many horticultural commodities has declined over time. It has been suggested that one reason for this decline is the development of newer cultivars with ever-increasing growth, but at the expense of nutrient content (Davis et al. 2004). If true, new breeding initiatives specifically designed to enhance nutritional value are required. Perhaps because of this, breeders are now attempting to increase the nutritional quality of fruit crops (Dorais and Ehret 2008).

Therefore, it could be summarized that essential soil elements that end up in the human diet are supplied through food from either plants that took the elements up from the soil during growth, or animal products after the animal obtained those essential elements from plants.

3.5 Soil Elements Necessary for Human Health

The 14 elements in the soil that are essential for plant growth are: nitrogen (N), calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sulfur (S), iron (Fe), copper (Cu), manganese (Mn), zinc (Zn), boron (B), chlorine (Cl), molybdenum (Mo), and sodium (Na). There are additional elements that are needed by some but not all plants such as cobalt (Co), bromine (Br), vanadium (V), silicon (Si), and nickel (Ni). In addition to these soil elements, hydrogen (H), oxygen (O), and carbon (C) are also essential for plant growth but are obtained from air and water. Most of these elements are also essential for human health as can be seen in the list below. Eleven elements comprise 99.9 % of the atoms found in the human body, subdivided into major and minor elements. Four major elements: H, O, C, and N make up about 99 % of the atoms in the body; seven minor elements: Na, K, Ca, Mg, P, S, and Cl make up an additional 0.9 % of the atoms in the body. In addition to these major and minor elements, there are approximately 18 additional elements considered essential in small amounts to maintain human life, although the exact number and identity of these elements is not universally agreed on by human health experts. These 18 additional elements, known as trace elements, include: lithium (Li), vanadium (V), chromium (Cr), manganese (Mn), iron (Fe), cobalt (Co), nickel (Ni), copper (Cu), zinc (Zn), tungsten (W), molybdenum (Mo), silicon (Si), selenium (Se), fluorine (F), iodine (I), arsenic (As), bromine (Br), and tin (Sn). Note that of the 29 elements considered essential for human life, 13 are essential plant nutrients obtained from the soil and another 5 are elements obtained from the soil that are needed by some, but not all, plants. Although the elements Cr, W, Se, F, I, As, and Sn are not considered essential for plant health, these elements are also found in trace amounts in plants that grow in soils containing them. Therefore, soils that provide a healthy, nutrient-rich growth medium for plants will result in plant tissues that contain many of the elements required for human life. In fact, most of the elements necessary for human life are obtained from either plant or animal tissues. Plant tissues are among the most important sources of Ca, P, Mg, K, Cu, Zn, Se, Mn, and Mo in the human diet (Table 14), and these elements are obtained by plants from the soil (Brevik 2009).

Therefore, it could be concluded that In most of the elements necessary for human life are obtained from either plant or animal tissues. Plant tissues are among the most important sources of Ca, P, Mg, K, Cu, Zn, Se, Mn, and Mo in the human diet, and these elements are obtained by plants from the soils.

3.6 Health and Nutrient Imbalances in Soil

There are several adverse health affects that can arise from nutrient deficiencies in soils. Iron deficiency is probably the most common example and may affect as many as five billion people, with about two billion considered anemic. Blood loss to parasites such as hookworms is another major cause of Fe deficiency. Hookworms are a disease-causing organism associated with the soil. The best source of Fe is meat,

Table 14 Some important plant-tissue sources and animal-product sources of elements essential to human life

Plant-tissue sources		Animal-product sources	
Element	Important sources	Element	Important sources
Ca	Kale, collards, mustard greens, broccoli	Ca	Dairy products
Cu	Beans, peas, lentils, whole grains, nuts, peanuts, mushrooms, chocolate	Cl	Dairy products, meats, eggs
I	Vegetables, cereals, fruit	Cu	Organ meats
K	Fruits, cereals, vegetables, beans, peas, lentils	Fe	Meats, especially red meat
Mg	Seeds, nuts, beans, peas, lentils, whole grains, dark green vegetables	K	Dairy products, meats
Mn	Whole grains, beans, peas, lentils, nuts, tea	Mo	Organ meats
Mo	Beans, peas, lentils, dark green leafy vegetables	Na	Dairy products, meats, eggs
P	Nuts, beans, peas, lentils, grains	P	Meats, eggs, dairy products
Se	Grain products, nuts, garlic, broccoli (if grown on high-Se soils)	Se	Meats from Se-fed livestock
Zn	Nuts, whole grains, beans, peas, lentils	Zn	Meats, organ meats

Adapted from Combs (2005)

especially red meat. High reliance on cereal-based diets low in meat, including cereal-based weaning foods for infants, can contribute to Fe deficiency. Low Fe in soils is rarely a problem except in arid regions. Another soil-related sickness is iodine (I) deficiency, which leads to goiter, severe cognitive and neuromotor deficiencies, and other neuropsychological disorders. The World Health Organization estimates that about one billion people are at risk for iodine deficiency disorders, and has made the elimination of iodine deficiency disorders a priority. Regions known to have soils deficient in iodine are mainly located in the high-altitude interior of continents, although iodine deficiency has been eliminated in many developed countries by introducing iodine supplements to foods such as salt and bread. Most iodine deficiency problems today are found in developing countries, particularly in South America, Africa, and southeast Asia.

A low level of selenium (Se) in soils used to grow grains and other food crops is associated with a Se-deficient diet. Inadequate intake of Se can cause Keshan disease, a heart disease, and Kashin-Beck disease, a disease that results in chronic disabling degenerative osteo-arthrosis. Insufficient Se levels may also be associated with cancer, cardiovascular disease, reproductive problems, muscle diseases, and asthma; in each of these cases research is still ongoing. Places that experience Se deficiency problems in the soil include the mountainous belt of northeast China to the Tibetan Plateau, parts of Africa, and the Pacific Northwest, Great Lakes region, and east coast in the United States (Brevik 2009).

Zinc deficiency causes stunted growth and hypogonadism. Some foods such as whole grains can be rich in Zn, but low in bio-available Zn which can then lead to Zn shortage in the human organism. Zinc deficient soils are widespread and include about half the worlds soils. Calcareous soils and leached, acidic soils are more likely to be Zn deficient. Copper deficiency has been shown to cause heart disease and has been observed in acidic Histosols, acidic sandy soils, and some alkaline sandy soils. Soil nutrient deficiencies may occur for a number of reasons. The most obvious reason is that the nutrient simply does not exist in sufficient quantity in the soil to lead to healthy plant growth. But there are also situations in which the nutrient is presented in plentiful amounts, but unavailable to plants. For example, zinc (Zn) deficiency commonly occurs in calcareous soils; phosphorus (P) is easily bound by Ca, Al, or Fe depending on the soil pH. In both cases, it is possible to have ample amounts of Zn or P in the soil for nutritional needs, but for inadequate amounts of Zn or P to be taken up by plants due to chemical reactions occurring within the soil binding up these elements (Brevik 2009).

Another way that nutrient deficiencies may occur is through antagonism, a process by which ions with the same valence will reduce the uptake of another ion. Examples of antagonism include arsenic (As) antagonizing P and strontium (Sr) antagonizing Ca. Some apple orchards in the United States have problems with As antagonism of P uptake because As-containing pesticides have been used in the past. There is also concern that Sr released during the Chernobyl nuclear disaster in 1986 could antagonize Ca uptake, especially in fields in northern Europe where Chernobyl fallout was highest. Because there are several different ways that soil nutrient deficiencies may occur, it is important to determine (i) what kind and (ii) why a deficiency is occurring. It is also important to note that several elements normally required in small amounts for human health can become toxic when present in high amounts, such as As, Cd, Fe, Zn, Cu, Cr, and others. Therefore, it is important not to overcorrect soil nutrient deficiencies. High levels of cadmium (Cd) in the soil, for example, can lead to high levels of Cd in plant tissues and Cd toxicity problems for people who consume plant materials raised in those soils. The itai-itai disease in Japan is a classic example of the problems created by high Cd levels. Mining in the Toyama Prefecture of Japan released Cd into the Jinzu River. The contaminated river water was used for rice irrigation, leading to high Cd levels in the rice and accumulation of Cd in the human body of people who ate the contaminated rice. High Cd levels in human tissues caused itai-itai disease, which is characterized by weak, brittle bones, pain in the legs and spine, coughing, anemia, and kidney failure. These problems eventually lead to the death of the victim. One of the main biologic issues created by high Cd levels in the human body is poor calcium metabolism (Brevik 2009).

Therefore, it could be concluded that there are several adverse health affects that can arise from nutrient deficiencies in soils. Soil nutrient deficiencies may occur for a number of reasons. The most obvious reason is that the nutrient simply does not exist in sufficient quantity in the soil to lead to healthy plant growth. But there are also situations in which the nutrient is presented in plentiful amounts, but unavailable to plants.

3.7 Plant Nutrition, Food Quality and Human Health

Good quality is important in almost all harvested crop products be they food, fodder or industrial raw materials. Because high-value food or feed is an essential precondition for the health of humans and domestic animals, the influence of plant nutrient supply on the quality of foodstuffs is of considerable importance. Farmers want to produce good-quality products and sell them for a remunerative price while consumers want to buy nutritious and safe food as cheaply as possible. The concept of quality is variable and any discussion on the subject should be based on a terminology that can distinguish between: (i) commercial quality, which determines the market price of the product, and (ii) nutritional quality or value, commonly called food value, which is relevant for health. Although the two concepts partly overlap, the respective priorities, namely, monetary vs. health aspects, set them apart. The commercial quality of a product defines the price at the market and is based on easily recognizable properties that, to a certain extent, also indicate its food value. The price of food for direct consumption depends mainly on easily detectable characteristics. The main features of commercial quality are: (i) external features, such as size, cleanliness and freshness; (ii) sensory features, such as taste, smell and color; (iii) keeping quality and shelf-life during storage and transport; and (iv) concentration of special important ingredients, e.g. protein concentration for baking-quality wheat, and ingredients for industrial processing (starch, sugar and oil) (Roy et al. 2006).

The nutritional value, commonly called food quality, includes all substances that contribute to complete nutrition of humans and animals. Consumers desire attractive, wholesome, nutritious food that is free of harmful substances. The nutritional value of food is determined by adequate concentrations of about 50 essential ingredients required by humans and also several beneficial substances that must be taken up in balanced proportions and at regular intervals. Food quality also includes safe food, which refers to the absence of health-harming substances. Good food should not contain: (i) excesses of plant nutrients that may be dangerous to health; (ii) toxic heavy metals from soils or from nutrient sources; (iii) toxic organic compounds, e.g. from organic waste materials; and (iv) radioactive contaminants. The "health" value of foods is complex and remains hidden for consumers. Moreover, the damaging effects of poor food quality on health mostly appear over a long period of time and consumers tend to neglect this aspect. However, it should be of central importance for their present and future well-being. The quality of food products depends on many factors. It is influenced primarily by: (i) genetic factors that determine the basic quality, specific to the kind of crop; (ii) climate factors, such as light, temperature and water supply, that enable plants to approach their genetic potential; and (iii) an adequate and balanced supply of all plant nutrients, often achieved by external nutrient application through fertilizers and manures (FAO 2006).

Fruits, nuts, and vegetables play a significant role in human nutrition, especially as sources of vitamins [C (ascorbic acid), A, thiamine (B_1), niacin (B_3), pyridoxine (B_6), folacin (also known as folic acid or folate) (B_9), E], minerals, and dietary fiber. Their contribution as a group is estimated at 91 % of vitamin C, 48 % of vitamin A, 30 % of folacin, 27 % of vitamin B_6, 17 % of thiamine, and 15 % of niacin in the U.S. diet. Fruits and vegetables also supply 16 % of magnesium, 19 % of iron, and 9 % of the calories. Legume vegetables, potatoes, and tree nuts (such as almond, filbert, pecan, pistachio, and walnut) contribute about 5 % of the per capita availability of proteins in the U.S. diet, and their proteins are of high quality as to their content of essential amino acids. Nuts are a good source of essential fatty acids, fiber, vitamin E, and minerals. Other important nutrients supplied by fruits and vegetables include riboflavin (B_2), zinc, calcium, potassium, and phosphorus. Examples of the phytochemicals in fruits and vegetables that have established or proposed positive effects on human health and their important sources are shown in Tables 15 and 16. Some changes in these tables are likely as the results of additional studies on effects of phytochemicals and their bioavailability on human health become available in the next few years. Meanwhile it is important to evaluate the validity and dependability of the results of every study before reaching conclusions for the benefit of consumers.

Fruits, nuts, and vegetables in the daily diet have been strongly associated with reduced risk for some forms of cancer, heart disease, stroke, and other chronic diseases (Goldberg 2003). Some components of fruits and vegetables (phytochemicals) are strong antioxidants and function to modify the metabolic activation and detoxification/disposition of carcinogens, or even influence processes that alter the course of the tumor cell. Although antioxidant capacity varies greatly among fruits and vegetables (Kalt 2002), it is better to consume a variety of commodities rather than limiting consumption to a few with the highest antioxidant capacity. The USDA 2000 Dietary Guidelines (USDA 2000) encourage consumers to: (1) enjoy five a day, i.e., eat at least two servings of fruits and at least three servings of vegetables each day, (2) choose fresh, frozen, dried, or canned forms of a variety of colors and kinds, and (3) choose dark-green leafy vegetables, orange fruits and vegetables, and cooked dry beans and peas often. In some countries, consumers are encouraged to eat up to ten servings of fruits and vegetables per day (Kader et al. 2004).

Therefore, it could be summarized that good crop quality is important in almost all harvested crop products be they food, fodder or industrial raw materials. Because high-value food or feed is an essential precondition for the health of humans and domestic animals, the influence of plant nutrient supply on the quality of foodstuffs is of considerable importance.

3.8 Plant Nutrition and Crop Quality

The effects of soil fertility and mineral nutrient supply on yield, carbohydrate and protein content of food crops are well documented, but little information is available about the effects of fertilization on phytochemicals. Soil fertility effects are related to soil type including physical and chemical properties. For instance, the total ascorbic acid and folic acid contents of green-flesh honeydew muskmelons were found to be higher when grown on clay loam versus sandy loam soil (Lester and Crosby 2002). Similarly, β-carotene content of orange-fleshed muskmelon fruit was higher in silty clay loam soil than in fine sandy loam soil (Lester and Eischen 1996). Such findings have implications for growing location as related to soil characteristics as well as climatic conditions. Mineral nutrients can influence phytochemical content

Table 15 Non-nutritive plant constituents that may be beneficial to human health

Constituent	Compound	Sources	Established or proposed effects on human-wellness
Phenolic compounds			
Proanthocyanins	Tannins	Apple, grape, cranberry, pomegranate	Cancer
Anthocyanidins	Cyanidin, malvidin, delphinidin, pelargonidin, peonidin, petunidin	Red, blue, and purple fruits (such as apple, blackberry, blueberry, cranberry, grape, nectarine, peach, plum & prune, pomegranate, raspberry, and strawberry)	Heart disease, cancer initiation, diabetes, cataracts, blood pressure, allergies
Flavan-3-ols	Epicatechin, epigallocatechin, catechin, gallocatechin	Apples, apricots, blackberries, plums, raspberries, strawberries	Platelet aggregation, cancer
Flavanones	Hesperetin, naringenin, eriodictyol	Citrus (oranges, grapefruit, lemons, limes, tangerine)	Cancer
Flavones	Luteolin, apigenin	Celeriac, celery, peppers, rutabaga, spinach, parsley, artichoke, guava, pepper	Cancer, allergies, heart disease
Flavonols	Quercetin, kaempferol, myricetin, rutin	Onions, snap beans, broccoli, cranberry, kale, peppers, lettuce	Heart disease, cancer initiation, capillary protectant
Phenolic acids	Caffeic acid, chlorogenic acid, coumaric acid, ellagic acid	Blackberry, raspberry, strawberry, apple, peach, plum, cherry	Cancer, cholesterol
Carotenoids			
Lycopene		Tomato, watermelon, papaya, Brazilian guava, Autumn olive, red grapefruit	Cancer, heart disease, male infertility
α-carotene		Sweet potatoes, apricots, pumpkin, cantaloupe, green beans, lima beans, broccoli, Brussel sprouts, cabbage, kale, kiwifruit, lettuce, peas, spinach, prunes, peaches, mango, papaya, squash and carrots	Tumor growth
β-carotene		Cantaloupes, carrots, apricots, broccoli, leafy greens (lettuce, swiss chard), mango, persimmon, red pepper, spinach, sweet potato	Cancer
Xanthophylls	Lutein, zeaxanthin, β-cryptoxanthin	Sweet corn, spinach, corn, okra, cantaloupe, summer squash, turnip greens	Macular degeneration
Monoterpenes	Limonene	Citrus (grapefruit, tangerine)	Cancer
Sulfur compounds	Glucosinolates, isothiocyanates, indoles, allicin, diallyl disulphide	Broccoli, Brussels sprouts, mustard greens, horseradish, garlic, onions, chives, leeks	Cancer, cholesterol, blood pressure, diabetes

Adapted from Kader et al. (2004)

Table 16 Summary of the nutritional value of the more common fruits per unit of fresh weight

Species	Fiber (mg/g)	Vit. A (IU/g)	Vit. C (μg/g)	Vit. E (μg/g)	Vit. B_1 (μg/g)	Vit. B_2 (μg/g)	Ca (μg/g)	Fe (μg/g)	K (mg/g)
Apple	24–27	0.53	46–58	1.81	0.14	0.14	72	1.45	1.15
Apricot	20–23	26.11	100–114	8.90	0.29	0.29	143	5.71	2.97
Avocado	50–62	6.21	71–173	20–27	1.07	1.07	107	10.71	6.43
Banana	24–26	0.81	87–93	1.02	0.42	1.02	59	3.39	3.96
Blackberry	53	1.65	210	11.70	0.28	0.42	319	5.56	1.96
Blueberry	24–27	1.00	97–131	5.72	0.48	0.48	62	1.38	0.89
Cherry	21–23	2.15	71–73	0.73	0.44	0.59	147	4.41	2.24
Cucumber	7	0.74	25–32	0.29	0.17	0.08	143	1.68	1.48
Grapefruit	11–16	0.1–2.6	312–382	1.28	0.33	0.16	116	0.83	1.38
Kiwi	30–34	1.75	928–974	14.6	0.26	0.53	263	3.95	3.32
Lemon	28	0.29	529–534	1.55	0.34	0.17	259	5.17	1.38
Mango	18	38.94	278	11.21	0.61	0.55	103	1.21	1.56
Melon Cantaloupe	8	32.24	367–425	–	0.38	0.19	112	1.88	3.09
Nectarine	17	7.36	51–54	7.72	0.15	0.44	51	1.47	2.12
Orange	24	2.05	533	1.83	0.84	0.38	397	0.76	1.81
Papaya	18	2.84	620	7.30	0.29	0.29	243	0.71	2.57
Pear	24–36	0.20	38–42	1.21	0.18	0.42	108	2.41	1.25
Pineapple	13	0.23	155–362	0.19	0.90	0.39	71	3.87	1.13
Plum	15	3.23	91–95	2.57	0.45	0.91	45	1.52	1.73
Pumpkin	11	10.82	49	–	0.33	0.78	151	5.71	2.30
Squash	11–19	1.96	150–170	1.24	0.62	0.35	203	4.42	1.95
Strawberry	22	0.27	566–592	2.78	0.18	0.66	138	3.61	1.66
Sweet pepper	17–20	6.3–57	804–1900	5.92–15.8	0.67	0.27	87	4.70	1.77
Tomato	12	6.23	125–189	5.32	0.61	0.50	50	4.44	2.22
Watermelon	4–5	3.66	81–99	0.49	0.79	0.20	79	1.97	1.16

Adapted from Dorais and Ehret (2008); data are from the USDA database
Vit vitamin

directly if they are structural constituents of the phytochemical in question or are involved in the immediate processes involved in their synthesis and/or storage. Phytochemical content could also be influenced indirectly if the mineral nutrient in question is involved in the synthesis of a substrate that is required for the biosynthesis of the phytochemical. Processes affecting the uptake, transport and metabolism of inorganic mineral nutrients will ultimately influence phytochemical profiles. Since nutrient supply can have varying effects on plant growth and development depending on soil characteristics, fertilization timing/amount and the physiological status of the plant, it is logical to expect that these factors will modify the phytochemical profiles of crops (Crosby et al. 2008).

Because only properly nourished plants can provide products of overall high quality, any fertilization that improves the supply of plant nutrients from deficiency to the optimal range raises the amount of nutritional substances. However, it is impossible to increase the concentrations of all valuable substances simultaneously. The nutrient supply required for high crop yields and for good food quality is nearly similar. In certain cases, e.g. baking quality of cereals or additional nutrient supply for highly productive animals, high-quality food and feed is produced by keeping supplies of some plant nutrients in the luxury supply range. The relationship between nutrient supply and the resulting change in quality of crop products has largely been established. In assessing the effects of added nutrients on produce quality, it should be remembered that: (i) increasing the nutrient supply from deficiency to the optimal range usually results in better produce quality; (ii) increasing supplies from optimal to the luxury range may increase, maintain or decrease quality; and (iii) extreme increases in supplies into the toxicity range reduce quality and must be avoided. Nutrients differ in their roles in plant production and produce quality as follows.

3.8.1 Nitrogen Supply and Product Quality

Nitrogen (N) is the nutrient element needed in greatest quantity by crops and is most often in short supply in the soil. High rates of nitrogen fertilization are usually associated with luxuriant vegetative growth, and increased leaf protein and pigment contents. Chlorophyll and carotenoids concentrations are positively correlated with plant N status. Kopsell et al. (2005) found that increasing the proportion of NO_3-N in nutrient solutions from 0 % to 100 % resulted in significant increases in both lutein and β-carotene concentrations in the leaf tissues of kale. For fruiting crops such as tomatoes and citrus, high rates of N fertilization have been reported to increase the level of carotenes and the B-vitamins and to reduce the concentration of vitamin C. The magnitude and direction of the response to N fertilization by phytochemicals seem to depend on the physiological status of the plant. During periods of slow growth, due perhaps to environmental stress, N fertilization seems to enhance production of phenolic phytochemical compounds involved in pathogen defense mechanisms. N fertilization has also been associated with reductions in the concentration of anthocyanin and catechins in apples and naringin and rutinoside in grapefruits (Patil and Alva 2002). High nitrogen application rates can interfere with potassium nutrition which, in addition to being a phytochemical, is also vital for many processes involved in the synthesis, transport and accumulation of other phytochemical compounds (Lester et al. 2005). Such competitive uptake inhibition interactions could alter the phytochemical contents and health properties of fruit and vegetable crops (Crosby et al. 2008).

Various N compounds in plants are important for quality assessment. The manner in which these are affected by N supplies is summarized below:

- **Nitrate**: Form of N taken up from soil; basis for protein synthesis; nitrate concentrations of plants are generally low, but it may be accumulated.
- **Crude protein**: This is an approximate measure of protein and some other N compounds. Crude protein concentration = N concentration × 6.25. The concentration of crude protein in wheat grain may be raised from 10 % to more than 15 %, thus improving the "baking quality" of the flour.

- Concentration of **pure protein** increases up to the optimal N supply level despite some counteracting dilution effect. Pure protein can be divided into several fractions:
  1. Prolamine and gluteline (low-value protein): Gluten is important for baking quality. N supply increases the prolamine content in grains, thus increasing the gluten concentration of grain kernels, which improves baking quality.
  2. Albumin and globulin (high-value protein), containing many essential amino acids. The concentration of albumen, which has high nutritional quality, increases with the concentration of pure protein.
- **Essential amino acids**: Nine protein constituents that are vital for humans and must be contained in food. Their concentration determines the biological value of the protein, expressed by the Essential Amino Acid Index (EAAI).
- **Vegetable proteins** have values of 50–70 % compared with 100 % in case of egg protein. The concentration of essential amino acids often increases up to the optimal N supply level, but it sometimes decreases through dilution, especially where there is luxury N consumption.
- **Amides:** These are important storage forms of N (e.g. asparagine or glutamine) found in leaves and vegetative reserve organs. Amides have only small nutritional value for humans, but, if heated, may produce substances with an undesirable odor. They can be a source of protein for ruminants.
- **Amines**: Various N-containing compounds present in small concentrations in plants. Some, e.g. choline, have important functions, whereas others, e.g. nitrosamines and betaine, are unwanted.
- **Cyclic N compounds** such as chlorophyll; N-containing vitamins such as vitamin B1; alkaloids, such as nicotine in tobacco; purine derivates, such as theobromine in cocoa (FAO 2006).

An increase in N supplies also causes several types of changes in other substances, e.g.: (i) the concentrations of carotene and chlorophyll increase up to the optimal N supply; (ii) the concentration of vitamin B1 in cereal grains increases until luxury N level; (iii) the concentration of vitamin C (ascorbic acid) decreases owing to the dilution effect; (iv) the concentration of oxalic acid, a harmful compound, increases in vegetables leaves (for human consumption) and in sugar beet leaves (used as fodder for cattle), especially after fertilization with nitrate-N; and (v) the concentration of HCN in grass increases slightly – while its normal concentrations appear to promote animal health, higher doses are toxic (Roy et al. 2006).

3.8.2 Phosphorus Supply and Product Quality

Phosphorus is an important mineral nutrient for optimal fruit and vegetable quality expression (Bruulsema et al. 2004). P nutrition effects on phytochemical content seem to be related to its role in metabolic energy (adenosine triphosphate, ATP) synthesis, generation of reducing power (nicotine adenine dinucleotide phosphate-oxidase, NADPH) and sugar phosphates serving as intermediates in various biosynthetic pathways. Paliyath et al. (2002) reported increased levels of the antioxidants anthocyanin in apples and lycopene in tomatoes in response to increased P fertilization, particularly under stressful conditions. Optimal P fertilization increased the percentage of red skin (an indicator of anthocyanin content) in two apple cultivars i.e. Red Delicious and McIntosh. Anthocyanins give fruits and vegetables their purple and red color appearance and have been shown to protect mammalian cell lipoproteins from oxidative damage (Kushad et al. 2003). Supplemental P fertilization also increased the yield of tomatoes, especially under stressful environmental conditions and such tomatoes had higher antioxidant activities than those without P supplementation (Crosby et al. 2008).

Owing to its many important roles in plant metabolism, the supply of P plays a central role in crop quality. Important quality indicators with respect to P are: (i) the P concentration and the composition of the plant P fraction; (ii) the concentration of other valuable substances that increase with better P supply; and (iii) the concentration of toxic substances that are often lower with increased P supply. The major P-containing compounds that are important for crop quality are:

- **Phosphate esters**: These are the products of phosphorylization, i.e. bonding of phosphate anions as phosphoryl group (-H_2P0_3) to organic molecules like sugars (R-O-H_2PO_3).
- **Phytin**: This is the main organic form of phosphate storage (Ca-Mg-salt of phytic acid, i.e. inositol hexaphosphoric acid). Phytin is the main P reserve of seeds and can constitute up to 70 % of total P. The proportion of phytin in vegetables such as potatoes is about 25 %, and phytin, like inorganic P, is utilized by all animals, but best by ruminants. However, for humans, phytic acid may reduce the bioavailability of Fe and Zn.
- **Phosphatides or phospholipids**: These are important constituents of cell membranes that contain phosphoryl groups (e.g. lecithin, a glycerophosphatide). These form only a small portion of total plant P (Roy et al. 2006).

The P concentration of food and fodder is an important quality criterion because insufficient P intake causes "*bone weakness*" and deformations, which were common in cattle before the use of mineral P fertilization. In contrast to N, the P supply to crops remains in the "*normal*" range and rarely reaches the luxury range on most soils. In other words, there is practically no danger of overfertilization with P, which may cause problems owing to excess phosphate in food or feed. When the P supply increases from deficiency to the optimal level, the total P concentration increases in the vegetative and reproductive parts, thus improving crop quality. The concentration of nucleic P increases only slightly, while the concentration of phosphatide-P remains approximately constant, and both occur in low concentrations. There is also a higher concentration of other value-determining substances, such as: (i) crude protein in green plant parts and essential amino acids in the grains; and (ii) carbohydrates (sugar and starch) and some vitamins, e.g. B1. Seed quality improves with P nutrition, which results in greater seedling vigour. On the other hand, the concentration of some other substances such as nicotine in tobacco, oxalic acid in leaves or coumarin in grass can be reduced (FAO 2006).

3.8.3 Potassium Supply and Product Quality

Among plant nutrients, potassium (K) is very closely associated with crop quality. It is required for good growth as well as for good crop quality, plant health, tolerance to various stresses and seed quality. By greatly affecting enzyme activity and through osmotic regulation, K affects the entire metabolism of the plant, especially photosynthesis and carbohydrate production. K is a vital element for plant and animal health playing an important role as a mineral nutrient in the synthesis and accumulation of other phytochemicals in plants. Even though K is not an integral part of any major structures, it plays a key regulatory role in many physiological processes vital to plant growth. Inadequate K supply is associated with reduced translocation of amino acids and minerals such as magnesium and calcium which are essential for fruit quality and postharvest shelf-life. Soil K supply and plant uptake are regulated by plant and environmental factors. For instance, in many species, young plants with actively growing roots are more efficient in obtaining K than mature plants. During reproductive development, competition for photoassimilates between developing fruits and vegetative organs may limit root growth and nutrient uptake, including K. This creates an apparent K deficiency that can slow down the many K dependent functions such as transport processes and stress tolerance, potentially reducing yield and quality. K seems to improve plant tolerance of various environmental stresses such as drought, low temperature or salinity all of which trigger cellular oxidative stress (Hodges et al. 2001). A plausible mechanism for the K-induced stress tolerance is through increased antioxidant activity of ascorbic acid.

Lester et al. (2005, 2006) found that supplementing soil K supply with foliar K applications during fruit development and maturation improved orange-flesh muskmelon fruit quality by increasing firmness, sugar content, ascorbic acid and β-carotene levels. It is unclear how high K content increases fruit ascorbic acid and β-carotene contents, but increased synthesis through enzyme activation is a possible mechanism. Increased phytochemical accumulation in fruits, through carefully timed, controlled K foliar fertilization could, therefore, enhance the health potential of fruits. Supplemental foliar K applications also increased the ratio of fructose to sucrose in muskmelon fruit (Lester et al. 2005). High fructose content is a desirable fruit characteristic since fructose is perceived to be sweeter than sucrose or glucose. In pink grapefruit, supplemental foliar K resulted in increased lycopene, β-carotene and vitamin C concentrations; however, higher levels of soil-applied K resulted in lower fruit total ascorbic acid levels (Patil and Alva 2002), perhaps highlighting the effects of timing as well as application method on K uptake and metabolism. Field experiments have also shown significant increases in daidzein, genistein and total isoflavone concentrations in soybean seeds in response to K fertilization on low and medium K soils (Vyn et al. 2002). Phytochemical contents of fruits and vegetables seem to be most responsive to K nutrition compared to the other major nutrients, perhaps a reflection of the numerous roles that K plays in plant and animal physiological processes (Crosby et al. 2008).

It could be concluded that K improves the quality of several products including tubers, fruits and vegetables. Increasing K supplies to plants up to the optimal level brings about the following changes:

- The concentration of carbohydrates increases owing to intensified photosynthesis, which results in larger concentrations of sugar, starch, fibres (cellulose), and also of vitamin C.
- The concentration of crude protein is reduced although the total amount is increased. This results from the dilution effect owing to the relatively greater increase in carbohydrate content. However, the more valuable fraction of pure protein may sometimes increase.
- The concentration of vitamin A and its precursor, carotene, increase.
- Losses of starch-containing tubers, such as potatoes, during storage are reduced through the prevention of decomposition of starch by enzymes.
- Unwanted "*darkening*" of potatoes is reduced. This phenomenon is caused by the formation of melanines and is particularly pronounced where K is deficient. Proper K supplies also prevent "*black spotting*" of potatoes upon cooking (Roy et al. 2006).

Unlike P, the K concentration is not a quality-determining component. Food usually contains more K than is required by humans or animals. Luxury supply of K in leaves may occur as a result of high K uptake. This is not detrimental but excess absorption of K by plants tends to reduce the uptake/concentration of Ca, Mg and Na, resulting in an imbalanced supply of these regulators of cell activity. K-induced Mg deficiency can decrease crop quality. On grassland, this can result in Mg deficiency in grazing animals. Some effects of K fertilizers on crop quality are not caused by K itself but by the accompanying anion such as chloride or sulphate. Application of potassium sulphate results in a higher starch concentration in potatoes than where potassium chloride is applied. This is because chloride disturbs the transport of starch from the leaves to the storage organ (tubers). Similarly, in the case of cigarette tobacco, potassium sulphate is the preferred source of K over potassium chloride because excess chloride can reduce the burning quality of the leaf (FAO 2006).

3.8.4 Calcium Supply and Product Quality

A good Ca supply is essential for osmotic regulation and pectin formation. The Ca concentration of food and fodder is important for a proper balance of the major cations. Adequate supplies of Ca prevent a number of crop quality problems, such as inner decay of cabbage, brown spot and bitter pit in apples, and empty shells in groundnuts. Although Ca supply may not increase the oil content in groundnut, the total oil yield increases as a result of the favorable effect of Ca on kernel yield. Many of the benefits of liming on crop quality stem less from Ca itself but more from indirect effects caused by changes in soil pH that increase the supplies of other elements (FAO 2006).

3.8.5 Magnesium Supply and Product Quality

A good supply of Mg increases the concentration of carbohydrates and also chlorophyll, carotene and related quality components that are important for grazing animals. The Mg concentration is an important quality criterion because the major cations (K, Ca and Mg) should be balanced in order to ensure the best nutritional quality in cereals. Adequate Mg increases grain size and boldness. It is also reported to increase the oil content in oilseeds. For example, excess K in grass can result in Mg deficiency leading to hypomagnesaemia or grass tetany in grazing animals (Roy et al. 2006).

3.8.6 Sulphur and Selenium Supply and Product Quality

As S is an important constituent of some essential amino acids (cysteine, cystine and methionine), S deficiency lowers protein quality. About 90 % of plant S is present in these amino acids. Some plants (crucifers) contain S in secondary plant substances, e.g. oil, whose synthesis is inhibited where S is deficient. Mustard and onions rely for pungency and flavor on S-containing substances and these are also useful for increasing resistance against infections in the plant. An adequate supply of S improves: oil percentage in seeds; seed protein content; flour quality for milling and baking; marketability of copra; quality of tobacco; nutritive value of forages; grain size of pulses and oilseeds; starch content of tubers; head size in cauliflower; and sugar content and sugar recovery in sugar cane (FAO 2006).

Some of the most convincing evidence of the influence of mineral nutrient supply on phytochemical content involves sulfur (S) and selenium (Se) fertilization of alliums such as onions and garlic, and crucifers such as broccoli and radish. Sulfur is an important constituent of the organo-sulfur and glucosinolate compounds that accumulate in these species and have been linked to positive health benefits including antiplatelet activity (Osmont et al. 2003). Numerous investigations have shown a strong positive correlation between the level of S fertility and organosulfur compounds in onions (Bloem et al. 2005). While the health benefits of sulfur nutrition are obvious, high soil S concentrations often result in increased onion pungency, a negative consumer preference trait. Goldman et al. (1996) demonstrated that growing onions in the presence of high S increased both the pungency and antiplatelet activity of the bulb. Since most consumers tend to prefer sweet (low pungent) onions, separating the health-benefiting trait (antiplatelet activity) from pungency is an important yet challenging task for breeders (Crosby et al. 2008).

Selenium is an essential micronutrient involved in protein synthesis in animals and may possess anti-carcinogenic properties. Selenium is closely related to and may be substituted for sulfur in metabolic pathways (Goldman et al. 1999). Barak and Goldman (1997) found that increasing selenium levels in a hydroponic system reduced sulfur uptake in onion but not sulfur concentration. In similar studies, Kopsell and Randle (1999a, b) found that while Se did not affect the content of total sulfur compounds in several onion cultivars grown in nutrient solutions, the relative levels of individual S compounds were altered. The antagonistic uptake interaction between Se and S is also apparent in glucosinolate accumulation in Brassica species when fertilized with Se or S. The Se content of rapid-cycling *Brassica oleracea* was increased while that of glucosinolates decreased as a result of fertilization with Na_2SeO_4 (Charron et al. 2001). Similarly, increasing the level of S resulted in reduced Se accumulation in hydroponic onion. This competitive uptake interaction between S and Se clearly indicates that nutrient management strategies designed to improve the health-promoting properties of crops must take into account the potential shifts and tradeoffs in whole-plant nutrient balance. Nonetheless, these field and controlled environment studies demonstrate that appropriate fertilizer management practices can alter the phytochemical content of target crops (Crosby et al. 2008).

3.8.7 Micronutrient Supply and Product Quality

Because micronutrients are involved in many metabolic processes, their adequate supply is a precondition for good food quality, especially with respect to the concentrations of proteins and vitamins. A survey of micronutrients in staple foods has been provided by Graham et al. (2001). The total concentration of the individual micronutrients is an important index of food and feed quality. However, some compounds containing micronutrients are utilized only partly by humans and animals. Because the concentrations of micronutrients are not determined routinely, their average concentrations are often considered for nutritional purposes although these may give only an approximate idea of actual concentrations. For example, in leafy vegetables, a wide variation may occur. The following concentrations (in milligrams per kilogram of dry matter) range from marginal deficiency to luxury supply but are not toxic: Fe 20–800, Mn 15–400, Zn 10–200 and Cu 3–15. The consequences for health are clear. If a person is to be supplied with vegetables rich in Fe for better blood formation, then products with higher Fe concentrations are certainly preferable. Micronutrient concentrations should not be increased up to the toxicity level. Toxic concentrations are not only detrimental as such, but also negatively affect the composition of organic food constituents. The following comments on individual micronutrients relate to food quality:

- B is required in good supply for fruit and vegetable quality. B deficiency causes spots and fissures that substantially reduce produce quality and market value.
- Cu is required in optimal amounts for high concentrations and quality of protein and also to avoid spottiness in some fruits. A shortage of Cu partly combined with Co deficiency in grass retards the growth of grazing animals, and metabolic disorders manifest in the so-called “lick disease”.
- Fe in green-leaf vegetables such as spinach is an important source of Fe for humans. Soils with high pH tend to produce products low in Fe.
- Mn raises the concentrations of some vitamins, such as vitamin A (carotene) and C, in food and fodder crops. For good fertility, grazing animals require Mn concentrations that are about double those required for optimal grass growth.

- Mo deficiency decreases protein content and quality because of the important functions of Mo in BNF and N metabolism. Mo is also involved in the formation of healthy teeth.
- Zn is connected with plant growth hormones. Therefore, a good supply is required in order to obtain full-sized products, as in the case of citrus fruits. Compared with Cu, the optimal range of Zn is large but its toxicity can become a problem on soils with excessive Zn.
- Excess micronutrients reduce food quality properties. However, this rarely is the case on most soils. An excess of chloride can aggravate salinity problems, adversely affect salt-sensitive crops and lower the quality of crops such as potato, tobacco and grapes (Roy et al. 2006).

Therefore, it could be concluded that the effects of soil fertility and mineral nutrient supply on yield, carbohydrate and protein content of food crops are well documented, but little information is available about the effects of fertilization on phytochemicals. Soil fertility effects are related to soil type including physical and chemical properties. Different plant nutrients affect directly or indirectly on the crop quality.

3.9 Nutritional Quality of Crops and Their Importance in Human Health

Numerous studies have shown that consumption of fruit and vegetables reduces the risk of developing cancer, cardiovascular disease, diabetes and obesity, neurodegenerative diseases and improves energy balance and weight management. Consequently, optimization of those compounds in fresh fruit which promote health and wellness is important, producing a cost-effective method for disease prevention. This can be partly achieved by traditional breeding and genetic manipulation, but pre-harvest factors can also contribute greatly to the nutritional quality of fresh fruits. In addition to yield and flavor considerations, new agricultural techniques are now integrating this important aspect. Fruits and fruit vegetables, such as tomato and sweet pepper, are known to contain nutritional components with several types of health-promoting actions. Fruit antioxidants are chemically diverse and are found in various locations and forms in fruit tissues and cells. Depending on the form of consumption (fresh, juice, processed) and type of tissue, the nutritional value may differ. For example, anthocyanins are generally found in fruit peel, while chlorogenic acid is in highest concentration in the core area and seeds with an intermediate level in the flesh and low level in the skin of apples. The red color of apple fruit, which is a major determinant of consumer appeal, is mainly due to the concentration of anthocyanin pigments, primarily cyanidin 3-galactoside (Ubi 2004). In bell peppers, ascorbic acid (vitamin C), pro-vitamin A (β-carotene), protein and some minerals are affected by fruit colour (red, white, yellow, orange, purple, brown or black) compared to the standard green fruit. The most abundant nutritive compounds found in fruits are carotenoids, vitamins, phenolics, minerals and fiber. Carotenoids are a major class of compounds providing precursors to essential vitamins and antioxidants. Vitamin C, mainly occurring as

L-ascorbic acid and to a lesser extent, as *L*-dehydroascorbic acid, is the most important vitamin found in fruits (Lee and Kader 2000). Vitamin A (β-carotene) and vitamin B_9 (folic acid) are also important human health phytochemicals found in fruits and vegetables. Vitamin C, carotenoids and phenolics are the main phytonutrients which possess antioxidant characteristics due to their electron-rich structure in the form of oxidizable double bonds and hydroxyl groups. Other compounds such as tocopherols and tocotrienols are also important antioxidants, but they are present in relatively low levels in fruits compared with nuts and grains (Dorais and Ehret 2008).

The current state of the knowledge indicates that minimally processed whole fruits and vegetables are excellent sources of phytochemicals that can help maintain optimal health. However, the current per capita consumption of fruits and vegetables is very low in many societies. Since the levels of certain phytochemicals are quite low or non-existent in some plant foods, one way of increasing the dietary intake of these compounds would be to increase their concentration in fruits and vegetables. It is quite apparent from the scientific literature that the concentration of secondary compounds, including phytochemicals, is regulated by genetic and environmental factors. The role of genetic factors has received considerable attention worldwide in an effort to develop improved varieties with enhanced concentrations. However, the contribution of environmental factors has received little attention even though environmental factors alone or in interaction with genetics might have a stronger influence on the synthesis and accumulation of phytochemical compounds. Continued progress towards a better understanding of these processes now makes it possible for development of specific strategies to alter the synthesis, accumulation, partitioning and diversity of phytochemicals in target crops (Crosby et al. 2008).

Fruits and vegetables contribute approximately 91 % of vitamin C, 48 % of vitamin A, 27 % of vitamin B_6, 17 % of niacin, 16 % of magnesium, 19 % of iron and 9 % of calories to the human diet. Other important nutrients supplied by fruits and vegetables, include folic acid, riboflavin, zinc, calcium, potassium and phosphorus (USDA 1983). Fruit and vegetable consumption has increased in response to growing health consciousness. Their consumption has been strongly linked do reduced risk of some forms of cancer, heart disease, stroke and other chronic diseases (Mirdehghan and Rahemi 2002). Fruits and vegetables are sources of antioxidants which modify the metabolic activation and detoxification/disposal of carcinogens, or even influence processes that alter the course of tumor cell growth (USDA 1983). Although antioxidant capacity varies greatly among fruits and vegetables, consumption of a variety of fruits and vegetables is preferred, over limiting fruit and vegetable consumption to those having the highest antioxidant capacity (Rahemi 2006).

Fruits, nuts, and vegetables play a significant role in human nutrition, especially as sources of vitamins [C (ascorbic acid), A, thiamine (B_1), niacin (B_3), pyridoxine (B_6), folacin (also known as folic acid or folate) (B_9), E], minerals, and dietary fiber (Wargovich 2000). Their contribution as a group is estimated at 91 % of vitamin C, 48 % of vitamin A, 30 % of folacin, 27 % of vitamin B_6, 17 % of thiamine, and 15 % of niacin in the U.S. diet. Fruits and vegetables also supply 16 % of magnesium, 19 % of iron, and 9 % of the calories. Legume vegetables, potatoes, and tree nuts (such as almond, filbert, pecan, pistachio, and walnut) contribute about 5 % of the per capita availability of proteins in the U.S. diet, and their proteins are of high quality as to their content of essential amino acids. Nuts are a good source of essential fatty acids, fiber, vitamin E, and minerals. Other important nutrients supplied by fruits and vegetables include riboflavin (B_2), zinc, calcium, potassium, and phosphorus. Fruits and vegetables remain an important source of nutrients in many parts of the world, and offer advantages over dietary supplements because of low cost and wide availability.

Therefore, it could summarized that numerous studies have shown that consumption of fruit and vegetables reduces the risk of developing cancer, cardiovascular disease, diabetes and obesity, neurodegenerative diseases and improves energy balance and weight management. Consequently, optimization of those compounds in fresh fruit which promote health and wellness is important, producing a cost-effective method for disease prevention.

3.10 Climate and Soils – Influence on Human Health and Society

Beyond the recognized importance of soils for agricultural production and its influence on humans and civilizations throughout history, there is potentially another, more subtle impact on the broad social health of human communities. Natural soil fertility has a profound influence on what kinds of agricultural activities i.e., production agriculture, grazing is undertaken by a society and, if production agriculture is practiced, on what kinds of crops can be grown. The soils also influence the productivity of agricultural efforts, and this in turn affects economic activity and societal stability. The Saharasia theory focuses on climate and the corresponding soils in an effort to explain the origins of social violence and warfare. Locations with rich, fertile soils and abundant productivity are seen as being among the last places on the planet where warfare developed. On the other hand, in places with frequent long droughts and poor soils, humans fought over scarce resources. This was particularly true in places that were once relatively productive but underwent desertification after human settlement. In these regions, the Saharasia theory argues that the most extremely patriarchal, authoritarian and violent world cultures developed in response to the resource poor conditions created by dry climates and low-fertility soils. Recall that the third primary aspect of health under the World Health Assemblys definition was social. While research in the area of soils and human health has been fairly limited in general, very little work has been done looking at soils and human health from the perspective of the health of an entire society. This is an area that deserves additional attention.

Therefore, it could be concluded that beyond the recognized importance of soils for agricultural production and its influence on humans and civilizations throughout history, there is potentially another, more subtle impact on the broad social health of human communities. Judicious management of soil, water and plant nutrients is one of the strategies to adapt to climate changes.

4 Degradation of Soil Fertility Versus Soil Fertility Management

Soils are the main basis of food production, and this will remain so even in the distant future in spite of some other possibilities. The capability of soils to produce plants resp. crops varies considerably from almost zero to very high. Under suitable climatic conditions, soils with high fertility are very productive in terms of plant growth and crop yields. Most soils of the world, however, possess only medium or low natural fertility. The present and future food security of the growing human population depends on the efforts of agricultural production which in turn depends on natural or improved high and sustained soil fertility (Finck 2006).

Soil degradation leads to a deterioration in soil quality, resulting in yield decline. Soil degradation lowers the actual or potential soil productivity in different ways:

- loss of the fertile topsoil components through erosion by water and wind;
- physical degradation (poor structure, compaction, crusting and waterlogging);
- chemical and biological degradation, e.g. decrease in organic matter and soil bioactivity, loss of nutrients through various routes, soil acidification or salinization with their accompanying problems of nutrient deficiencies,
- Toxicities and imbalances.

Soil degradation is widespread in many parts of the world. The basic causes of soil degradation are the result of human activities such as deforestation, overgrazing and poor soil management. Factors that cause soil degradation are interrelated. About 1,200 million ha worldwide are considered to be affected by soil degradation, mostly by erosion. It has been estimated that human-induced soil degradation has affected 46 million ha in Africa and 15 million ha in Asia (FAO 2000a). Out of these, 25 % of such soils in Africa and 67 % in Asia are moderately to severely affect (Table 17; FAO 2006).

Soil fertility is not a stable property but a dynamic one. There are widespread problems of soil fertility degradation under many cropping systems even on soils with good initial soil fertility. The result of such a decline is a reduced nutrient supply, which reduces crop yields. From plant nutrition considerations, chemical degradation of the soil, particularly its fertility status, is of greatest concern. Losses of nutrients from soil can be caused by soil erosion, leaching, crop removal or in the form of gases (as in case of N and to a lesser extent S). Nutrient removal by crop products compared with external nutrient inputs can be similar, higher or lower. Negative nutrient balances result where nutrient removals exceed nutrient additions. These are a cause of soil fertility depletion or nutrient mining. Positive nutrient balances indicate a buildup or improvement in soil fertility (FAO 2006).

Judicious management of soil, water and plant nutrients is one of the strategies to adapt to climate change. Nutrient depletion and imbalance in soil adversely affect crop growth and yield, and are serious issues in soils of SSA and elsewhere in Asia, Central America and the Caribbean. Tan et al. (2005) estimated that globally nutrient depletion occurs at the rate of 18.7 kg ha^{-1} $year^{-1}$ of N, 5.1 kg ha^{-1} $year^{-1}$ of P and 38.8 kg ha^{-1} $year^{-1}$ covering 59, 85 and 90 % of harvested area in 2000. Tan and

Table 17 General soil test limits used for classifying soils into different fertility classes

		General fertility class		
Nutrient	Method/extractant	Low	Medium	High
N (% organic C)	Organic carbon	<0.5	0.5–0.75	>0.75
N (kg/ha)	Alkaline permanganate	<280	280–560	>560
P_2O_5 (kg/ha)	Sodium bicarbonate	<23	23–56	>56
K_2O (kg/ha)	Ammonium acetate	<130	130–335	>335
S (kg/ha)	Heat soluble, $CaCl_2$	<20	20–40	>40
Ca (% of CEC)	Ammonium acetate	<25		
Mg (% of CEC)	Ammonium acetate	<4		
Zn (μg/g)	DTPA	<0.6	0.6–1.2	>1.2
Mn (μg/g)	DTP A	<3.0		
Cu (μg/g)	DTPA/ammonium acetate	<0.2		
Fe (μg/g)	DTPA	<2.5–4.5		
Fe (μg/g)	Ammonium acetate	<2.0		
B (μg/g)	Hot water	<0.5		
Mo (μg/g)	Ammonium oxalate	<0.2		

Adapted from Roy et al. (2006)

colleagues estimated the global annual nutrient deficit at 5.5 Tg of N, 2.3 Tg P, and 12.2 Tg K, causing a total production loss of 1,136 million tons of food grains. Soil nutrient depletion is attributed to lack of or insufficient use of fertilizers, unbalanced fertilization, and losses caused by erosion, leaching, volatilization and weeds. Increasing the input of plant nutrients into the ecosystem is crucial to creating a positive nutrient budget. Nutrients may be applied from inorganic or organic sources (Goulding et al. 2007). Nitrogen is the most limiting factor in crop production, and its use efficiency remains low because of the severe losses caused by volatilization and leaching (Eickhout et al. 2006). Nitrogen management is closely related to the soil C pool and its dynamics, and soils of the tropics are highly depleted of their soil C pool because of extractive farming practices used for centuries and millennia. Using integrated nutrient management (INM) techniques is important for enhancing and sustaining soil fertility. INM involves combined use of mineral and organic fertilizer sources along with the adoption of legume-based, tree-based and animal-based farming systems. Several studies conducted in sub-Saharan Africa (SSA) and South Asia (SA) have documented the long-term and positive impacts of using INM techniques for improving soil fertility. The use of fire must be minimized because of numerous adverse impacts on ecosystem processes (Shriar 2007). The direct link between anthropogenic emissions and atmospheric abundance of CO_2 (Broecker 2007), necessitates adoption of mitigation strategies, along with afforestation and restoring prairie wetlands. There are numerous strategies of mitigating climate change. Improving soil quality through C sequestration is one of these options (Lal 2009d).

Therefore, it could be concluded that soils are the main basis of food production, and this will remain so even in the distant future in spite of some other possibilities.

The present and future food security of the growing human population depends on the efforts of agricultural production which in turn depends on natural or improved high and sustained soil fertility.

4.1 Improving Soil Fertility

In many situations, soil degradation can be reversed by required inputs and improved management. However, once the topsoil has been lost, the damage has been done and there is little or no possibility of restoring it. Loss of top soils is one of the worst forms of soil degradation. Some generally suggested measures for improving soil fertility/productivity are:

1. ***Physical factors***:
    - Shallow main rooting zone (deeper cultivation where possible);
    - Hard layers in subsoil (mechanical destruction of such layers);
    - Very sandy soil (use of organic manure on priority);
    - Poor structure (addition of organic matter, mulches, and amendments).
2. ***Chemical factors*****:**
    - Strong acidity (application of limestone, avoiding acid-forming fertilizers); strong alkalinity (apply amendments such as gypsum and pyrites, green manuring);
    - Strong salinity (leaching with non-saline water, growing salt-tolerant crops, green manuring);
    - Nutrient toxicities (use of suitable amendments, drainage, tolerant crops);
    - Low nutrient status (application of deficient nutrients through mineral, organic and biological sources);
    - Nutrient fixation (application of suitable amendments, placement of fertilizers).
3. ***Biological factors*****:**
    - Low organic matter (application of organic manures, compost, green manure);
    - Poor microbial activity (improvement of aeration, drainage, correction of pH, organic inputs) (FAO 2006).

Even under conditions of low input cropping and with nutrient depleted soils, fertility degradation can be reversed in acid soils. The first step should be a better P supply with phosphate fertilizers, possibly with some lime application and N input via N fixation by legumes, resulting in a spiraling upwards process. While soil improvements may result in 50 % higher yields at a low in put level, more impressive results can be obtained at a high-input level. A good example is that of the formerly degraded and low-yielding, but now highly productive soils of Western Europe with present wheat yields of 8–10 t ha^{-1}. The original cereal yield ranged from 0.5 to 1.5 t ha^{-1}, a yield that can still be observed in unfertilized control plots of old field experiments and on the fields of millions of farmers in many parts of Asia, Africa and Latin America (Table 18; FAO 2006).

Table 18 Environmental problems associated with fertilizer use and possible solutions

Problem	Cause mechanism	Possible solutions
Groundwater contamination	Leaching of weakly held nutrient forms such as nitrate (most important), chloride, sulphate and boric acid	Balanced use of fertilizers; optimal loading rates of animal slurry, organic manure and wastewaters; improved practices for increasing N efficiency; including use of nitrification inhibitors, coated fertilizers and deep placement of N fertilizer super granules where economic; integrated N and water management
Eutrophication	Nutrients carried away from soils with erosion, surface runoff or groundwater discharge	Reduce runoff, grow cover crops, adopt water harvesting and controlled irrigation, control soil erosion
Methaemo-globinaemia	Consumption of high nitrate through drinking-water and food	Reduce leaching losses of N, improve water quality
Acid rain and ammonia redeposition	Nitric acid formed by the reaction of N oxides with moisture in the air, ammonia volatilization and sulphur dioxide emissions	Reduce denitrification, adopt proper N application methods to reduce NH3 volatilization, correct high soil pH, increase CEC by organic additions
Stratospheric ozone depletion and global warming	Nitrous oxide emission from soil as a result of denitrification	Use of nitrification inhibitors, urease inhibitors, increase nitrogen-use efficiency, prevent denitrification
Itai-itai (ouch-ouch) disease	Eating rice and drinking water contaminated with Cd	Soil management such as liming or water control in rice fields, monitoring Cd content of PR and finished fertilizers
Fluorosis in animals	Ingestion of soil or fertilizer treated with high fluoride PR	Monitor the F content of PR applied directly to acid soils

Adapted from Roy et al. (2006)

Soils provide plants with a medium in which roots can anchor themselves and support their canopies, and from which they can tap reserves of water and nutrients. To supply adequate space, water and nutrients, a good soil should be deep, permeable, porous, with good water and nutrient retention capacity and rich in a balanced amount of minerals and organic compounds. Most soils do not have these ideal characteristics. However, in their long period of evolution, plants adapted to almost any soil condition and covered most of the earth's surface, except for the harshest sites. Under these natural conditions, soil and plants maintain a continuous interaction where changes in the characteristics of soils and vegetation are mutually interdependent. Mineral nutrients cycle from soil to plants and back to the soil: absorbed by roots, incorporated into plant tissues, sometimes consumed by animals, then returned to the soil as litter which is decomposed by soil organisms. Soil losses by erosion are compensated by slow soil formation processes, so that a soil layer forms nearly everywhere, except steep slopes. These quasi-stable situations are considered sustainable (Sampaio and Menezes 2003).

Agriculture may alter this stability and increasingly so as more vegetation and soils are changed by human intervention. Questioning the need for this intervention is beyond the scope of this article since it ultimately refers to growth of the human population and its increasing demand for food and other plant products. These demands have led to an increasing use of marginal soils and greater inputs to raise agricultural output. Agriculture disrupts nutrient cycles by exporting nutrients from agricultural fields to consumer sites. Thus, all agriculture eventually leads to nutrient depletion, an unsustainable situation, unless nutrients are replenished from outside. To replenish nutrients and to correct for original imbalances, fertilization and liming have been widely utilized. However, these inputs can create further imbalances in the availability of plant nutrients (Sampaio and Menezes 2003).

Agriculture requires the partial or total substitution of natural plant cover by one or more species, often with a vegetation structure different from the original. This substitution requires management. Elimination of the original cover requires cutting, removal or burning and weeding. This results in nutrient loss from the system. Establishment of the new plants requires seeding and frequently seed bed preparation by plough and harrow. Soil exposure to rain and wind under incomplete plant cover may result in erosion. To prevent water erosion, slopes may be altered by contour plowing, terraces and other conservation practices. This movement of soil and traffic of machines may result in the disruption of soil structure, compaction and surface crusting. Soil movement and disruption may also result in increased mineralization of soil organic matter to CO_2 with a double effect: further impoverishment of soil structure and release of nutrients which may be lost or absorbed and harvested. These processes are fastest under tropical and humid conditions (Sampaio and Menezes 2003).

Agriculture is frequently limited by water availability. Irrigation solves the problem but may create new ones if it increases soil salinity, alters the balance of nutrients and reduces soil permeability, or also if the water table rises too close to the surface, at lower landscape positions, creating waterlogged conditions, which most crop roots cannot tolerate. Since it alters so many ecosystem characteristics, agriculture disrupts the original stability of any site where it is established. A new stabilization may be achieved and sound management practices may create stability at an appropriate production level. However, with continuous human intervention, there is always the risk of change beyond the limits of resilience and sustainability. Although widely used, sustainability is not a clear and precise concept. It involves a concern for the environment and for its future condition. But it may be viewed from different perspectives and there is no set of acceptable measures to judge its value in any one place. Its use in agriculture is even more complicated because changes are inherent in the system. Technological advances may or may not solve present and future limitations and social and economic change may make present systems outdated. Sustainability can be viewed from this broad perspective, including not only maintenance of soil productivity but also maintenance of a clean environment, farm profitability, and fair distribution of social benefits. The following discussion of sustainability will be mostly restricted to agricultural productivity and pollution potential (Sampaio and Menezes 2003).

Therefore, it could be summarized that, soils provide plants with a medium in which roots can anchor themselves and support their canopies, and from which they can tap reserves of water and nutrients. To supply adequate space, water and nutrients, a good soil should be deep, permeable, porous, with good water and nutrient retention capacity and rich in a balanced amount of minerals and organic compounds.

5 Harvest and Postharvest

The harvest is the process of gathering mature crops from the fields. Reaping is the cutting of grain or pulse for harvest, typically using a scythe, sickle, or reaper. The harvest marks the end of the growing season, or the growing cycle for a particular crop, and this is the focus of seasonal celebrations of many religions. On smaller farms with minimal mechanization, harvesting is the most labor-intensive activity of the growing season. On large, mechanized farms, harvesting utilizes the most expensive and sophisticated farm machinery, like the combine harvester. Harvesting in general usage includes an immediate post-harvest handling, all of the actions taken immediately after removing the crop-cooling, sorting, cleaning, packing-up to the point of further on farm processing, or shipping to the wholesale or consumer market. Harvest timing is a critical decision, that balances the likely weather conditions with the degree of crop maturity. Weather conditions such as frost, rain (resulting in a “wet harvest”), and unseasonably warm or cold periods can affect yield and quality. An earlier harvest date may avoid damaging conditions, but result in poorer yield and quality. Delaying harvest may result in a better harvest, but increases the risk of weather problems. Timing of the harvest often amounts to a significant gamble. Harvesting is the gathering of plant parts that are of commercial interest. These include: fruits e.g. tomatoes, peppers, apples, kiwifruits, etc.; root crops e.g., beets, carrots etc; leafy vegetables such as spinach and Swiss chard; bulbs-onions or garlic; tubers e.g. potatoes; stems e.g. asparagus; petioles such as celery and inflorescences e.g. broccoli, cauliflower etc (Simson and Straus 2010).

Harvest of fruit and vegetable crops occurs in different times of the year depending on cultivar, water regime, climate conditions, pest control, cultural practices,

Fig. 12 The good soil management can be helped to cultivate okra crop in Shalateen district, Egypt. Organic farming for okra and during December the harvesting is established in this area (Photo by H. El-Ramady)

exposure to direct sunlight, temperature management and maturity index, among other important pre-harvest factors. After crops are harvested, respiration is the major process to be controlled. Postharvest physiologists and food scientists do not have many options to interfere with the respiratory process of harvested commodities, since they are largely dependent on the product specific characteristics. In order to minimize undesirable changes in quality parameters during the postharvest period, growers and entrepreneurs can adopt a series of techniques to extend the shelf-life of perishable plant products. Postharvest technology comprises different methods of harvesting, packaging, rapid cooling, storage under refrigeration as well as modified (MA) and controlled (CA) atmospheres and transportation under controlled conditions, among other important technologies. This set of strategies is of paramount importance to help growers all over the world to withstand the challenges that climate changes will impose throughout the next decades (Figs. 12 and 13; Moretti et al. 2010).

Harvesting is the gathering of plant parts that are of commercial interest. These include, for example, the following: *fruits* – tomatoes, peppers, apples, kiwifruits; *root crops* –beets and carrots; *leafy vegetables* – spinach and Swiss chard; *bulbs* – onions and garlic; *tubers* – potatoes; *stems* – asparagus; *petioles* – celery; and, *inflorescences* – broccoli and cauliflower. Harvest marks the end of the growing period and the commencement of market preparation or conditioning for fresh products. Harvesting can be performed by hand or mechanically. However, for some crops, such as onions, potatoes and carrots, it is possible to use a combination of

Fig. 13 The good soil management can help to cultivate different vegetable crops in Shalateen district, Egypt. Because of the high temperature in December around 25 °C the different crops harvested so early comparing with crops in Delta of Egypt (Photo by H. El-Ramady)

both systems. In such cases, the mechanical loosening of soil facilitates hand harvesting. The choice of one or other harvest system depends on the type of crop, destination and acreage to be harvested. Fruits and vegetables for the fresh market are hand harvested while vegetables for processing or other crops grown on a large scale are mainly harvested mechanically (FAO 2004).

Therefore, it could be concluded that harvesting is the gathering of plant parts that are of commercial interest. Harvest of fruit and vegetable crops occurs in different times of the year depending on cultivar, water regime, climate conditions, pest control, cultural practices, exposure to direct sunlight, temperature management and maturity index, among other important pre-harvest factors.

5.1 Harvest Recommendations

The main criteria used for harvesting most fruits and vegetables are color and the degree of development, or both. It is, however, common to combine these with other objective indices. These include, for example, firmness (apple, pear, stone fruits), tenderness (peas), starch content (apple, pear), soluble solid content (melons, kiwifruit), oil content (avocado), juiciness (citrus), sugar content/acidity ratio (citrus), aroma (some melons). For processing crops, it is important to keep a constant flow of raw material in the harvesting schedule. It is therefore normal practice to calculate the number of days from flowering and/or the accumulation of heat units. Harvesting involves a number of other activities undertaken in the field including those of commercial interest.

Examples of operations to facilitate preparation for the market include pre-sorting and the removal of foliage and other non-edible parts. In some cases, the product is completely prepared for the market in the field. The normal practice however is to empty the harvest containers into larger ones for transportation to the packinghouse where they are dry- or water-dumped onto grading lines. Most bruising occurs while these activities are being undertaken. It has a cumulative impact that can affect the final quality of the produce. It could be recommended the following items for vegetable harvesting:

- If the time of day can be selected, it is recommended to harvest during the cool morning hours when products are more turgid. Furthermore, less energy is required for refrigeration.
- Harvesting maturity is a function of the distance to the destination market: those within close proximity allow ripening on the plant.
- Harvested produce must be kept in the shade until the time of transportation.
- Avoid product bruising. Scissors or knives used for harvesting should have rounded ends to prevent punctures and be sharp enough to prevent tearing off. Harvest containers should be cushioned, smooth and free of sharp edges. Do not overfill field containers and move them carefully. Minimize drop heights when transferring produce to other containers.
- Train harvest laborers to handle produce gently and to identify correct maturity for harvest. Wear gloves during harvesting and handling to avoid damage to fruits (FAO 2004).

The main advantages of mechanized harvesting are speed and the reduced costs per ton harvested. However, because of the risk of mechanical damage, this system can only be used on crops that require a single harvest. A decision to purchase the necessary equipment calls for careful evaluation of the initial investment required as well as the maintenance costs. The long period in which equipment may have to stand idle should also be taken into consideration. In addition, the entire operation should be designed specifically for mechanized harvesting. Market preparation (grading, cleaning, packing, etc.) and trade systems should be set up to handle large volumes of produce. Harvesting involves a number of other activities undertaken in the field including those of commercial interest. Examples of operations to facilitate preparation for the market include pre-sorting and the removal of foliage and other non-edible parts. In some cases, the product is completely prepared for the market in the field. The normal practice however is to empty the harvest containers into larger ones for transportation to the packinghouse where they are dry- or water-dumped onto grading lines. Most bruising occurs while these activities are being undertaken. It has a cumulative impact that can affect the final quality of the produce. Hand harvesting is particularly suitable for crops with an extended harvest period. The rate of harvesting can be increased by hiring more workers if, for example, ripening is accelerated because of climatic conditions and the crop must be harvested quickly. The main benefit of hand harvesting compared with mechanized harvesting is that humans are able to select the produce at its correct stage of ripening and handle it carefully. The result is a higher quality product with minimum damage. This is important for tender crops. Adequate training, including supervision of the harvest crew, is required (FAO 2004).

In agriculture, postharvest handling is the stage of crop production immediately following harvest, including cooling, cleaning, sorting and packing. The instant a crop is removed from the ground, or separated from its parent plant, it begins to deteriorate. Postharvest treatment largely determines final quality, whether a crop is sold for fresh consumption, or used as an ingredient in a processed food product. The most important goals of post-harvest handling are keeping the product cool, to avoid moisture loss and slow down undesirable chemical changes, and avoiding physical damage such as bruising, to delay spoilage. Sanitation is also an important factor, to reduce the possibility of pathogens that could be carried by fresh produce, for example, as residue from contaminated washing water. After the field, post-harvest processing is usually continued in a packing house. This can be a simple shed, providing shade and running water, or a large-scale, sophisticated, mechanized facility, with conveyor belts, automated sorting and packing stations, walk-in coolers and the like. In mechanized harvesting, processing may also begin as part of the actual harvest process, with initial cleaning and sorting performed by the harvesting machinery.

Initial post-harvest storage conditions are critical to maintaining quality. Each crop has an optimum range for storage temperature and humidity. Also, certain crops cannot be effectively stored together, as unwanted chemical interactions can result. Various methods of high-speed cooling, and sophisticated refrigerated and atmosphere-controlled environments, are employed to prolong freshness, particularly in large-scale operations. Regardless of the scale of harvest, from domestic garden to industrialized farm, the basic principles of post-harvest handling for most crops are the same: handle with care to avoid damage (cutting, crushing, and bruising), cool immediately and maintain in cool conditions, and cull (remove damaged items).

Therefore, it could be conclude that postharvest handling is the stage of crop production immediately following harvest, including cooling, cleaning, sorting and packing. The instant a crop is removed from the ground, or separated from its parent plant, it begins to deteriorate. Postharvest treatment largely determines final quality, whether a crop is sold for fresh consumption, or used as an ingredient in a processed food product.

5.2 The Postharvest Environment

The postharvest environment represents a particular sector for the development of BC. Wounds made during harvesting and fruit handling can be protected from wound invading pathogens with a single postharvest application of the antagonist directly to wounds, using existing delivery systems (drenches, sprayers, dips). Once harvested, fruits are placed in cold storage for various periods of time ranging from a few days to months, depending on the commodity. The short period between harvesting and placing fruit in storage, from less than a day to a few days, requires rapid antagonist action. Once fruit is placed in cold storage, metabolic rates of the host and associated microflora will decline depending on the temperature regime selected. The search for antagonists to control postharvest wound invading pathogens should be narrowed to rapid colonizers of the wound site that can still be metabolically active at low storage temperatures. Peculiar difficulties are present in the control of postharvest diseases: the disease control level required is extremely high (also 95–98 %); the nutritional safety imposes special care to the direct use of living microorganisms on food products; the potential market to employ a biofungicide expressly developed for postharvest use is relatively small. On the other side, the possibilities of success for postharvest biological means can be numerous. The storage conditions partially controlled, such as temperature and humidity, can switch the host-pathogen-antagonist equilibrium towards the antagonist and the laboratory trials and results have a higher possibility to be transferred into practice. Furthermore, biotic interference is minimal so antagonists encounter minimal competition from indigenous microorganisms. Consequently, biological control (BC) of postharvest diseases tends to be more consistent than BC under field conditions, and the occasional variation in performance usually can be traced to nonstandard procedures or conditions. The application site of the antagonist, which is the fruit, is limited, permitting an increase of the BCA efficacy and avoiding the presence of some interfering factors. Finally, the high value of fruit can justify a treatment with a product relatively expensive, whereas under field conditions this usage might not be cost effective (Spadaro 2011).

Therefore, it could be conclude that the postharvest environment represents a particular sector for the development of biological control. Wounds made during harvesting and fruit handling can be protected from wound invading pathogens with a single postharvest application of the antagonist directly to wounds, using existing delivery systems.

5.3 Postharvest Physiological Disorders of Fresh Crops

Postharvest physiological disorders are defined as those disorders that occur in fresh crops after harvest resulting from altered metabolism in response to imposition of stresses, and that are manifested as visible symptoms of cell death in the susceptible plant part. Physiological disorders are distinct from the many other undesirable postharvest changes in quality, such as water loss (wilting), loss of chlorophyll, softening, and other ripening related events associated with normal senescence, which affect fresh crop storage potential and thus marketability. The definition also excludes a number of direct postharvest injuries that can occur as a result of mechanical damage e.g., bruising and other browning reactions associated with harvesting and handling, freezing damage, and exposure to gases or chemical solutions e.g., ammonia leaks in cold storage, or skin damage from salts and antioxidants used in postharvest treatments. Pathological disorders are also distinct, but it is not uncommon for diseases to be associated with physiological disorders, especially as secondary infections. Postharvest physiological disorders, by definition, develop after harvest. However, an overlap between pre- and postharvest expression can exist, and some disorders, especially those that are nutrition-related, may develop in fresh crops both on the parent plant and after harvest. In addition, it is important to note that preharvest factors, including climate, maturity at harvest, nutrition, and field management methods, can markedly affect susceptibility and tolerance of fresh crops to postharvest stresses. Therefore, considerable variation in the severity and timing of disorder expression can be observed even in the same crop, both within and among apparently similar lots of the same cultivar or strain. A wide range of physiological disorders has been identified in harvested fresh crops. Those affecting the major commercial crops have been relatively well defined, although understanding of the biochemical basis for their development is often incomplete. The literature is most extensive for fresh crops that are stored for long periods, and of all crops, the apple probably has the widest range of commercially significant physiological disorders. The etiology of some disorders, particularly on minor crops, is often less complete. This article focuses on disorders associated with calcium deficiency, chilling injury, carbon dioxide and oxygen, and ethylene, and on hypotheses for disorder development (Watkins 2003).

Therefore, it could be concluded that postharvest physiological disorders could be defined as those disorders that occur in fresh crops after harvest resulting from altered metabolism in response to imposition of stresses, and that are manifested as visible symptoms of cell death in the susceptible plant part. Physiological disorders are distinct from the many other undesirable postharvest changes in quality, such as water loss or wilting, loss of chlorophyll, softening, and other ripening related events associated with normal senescence, which affect fresh crop storage potential and thus marketability.

5.4 Disorders Associated with Calcium Deficiency

Most information on nutrition and physiological disorders has centered on calcium. In addition to those described for apple, a wide range of disorders associated with calcium deficiency are recognized (Table 19). Foliar symptoms of calcium deficiency are rarely observed, but disorders of fruits, storage roots, tubers, and compact leafy vegetables have been well described. These disorders can vary from localized symptoms in the case of bitter pit in apples or cavity spot of carrots to extensive cell death in disorders such as senescent breakdown of apples. The soil solution usually provides an adequate supply of calcium to the plant, and therefore calcium deficiencies normally result from inefficient calcium distribution rather than limited calcium uptake. Calcium is moved to a greater extent in the xylem than in the phloem. A high growth rate of susceptible tissues can increase the occurrence of calcium deficient disorders, and calcium movement into fast-growing tissues, such as leaves, is much

Table 19 Physiological disorders associated with calcium deficiency

Crop (scientific name)	Physiological disorder
Celery (*Apium graveolus*)	Black heart
Brussels sprouts (*Brassica oleracea*) Group Gemmifera	Internal browning
Cabbage (*Brassica oleracea*) Group Capitata	Internal tipburn
Pepper (*Capsicum annuum*)	Blossom end rot
Carrot (*Daucus carota*)	Cavity spot
Strawberry (*Fragaria ananasa*)	Tipburn
Lettuce (*Lactuca sativa*)	Tipburn
Tomato (*Lycopersicon esculentum*)	Black seed, blossom end rot
Mango (*Manifera indica*)	Soft nose
Avocado (*Persea americana*)	End spot
Snap or green beans (*Phaseolus vulgaris*)	Hypocotyl necrosis
Pear (*Pyrus communis*)	Cork spot, bitter pit
Potato (*Solanum tuberosum*)	Spout failure, tipburn, internal rust spot
Chicory (*Cichorium intybus*)	Blackheart, tipburn
Parsnip (*Pastinaca sativa*)	Cavity spot

Adapted from Watkins (2003)

greater than into low-transpiring organs, such as fruits and storage organs. Water shortage or irregular water supply can also reduce calcium translocation into these organs. In contrast, magnesium and potassium translocation is less affected, resulting in a high magnesium plus potassium to calcium ratio in the tissue. The role of calcium in plant tissues is assumed to be primarily in the maintenance of membrane structure and function, and of cell wall structure. Calcium stabilizes membranes by bridging phosphate and carboxylate groups of phospholipids and proteins at membrane surfaces (Watkins 2003).

Calcium-deficiency disorders are probably related to impaired selective permeability of the membrane to many solutes, membrane disorganization, and loss of many membrane functions, and eventually loss of compartmentation in the cell. An involvement of calcium in cell walls also seems critical as the cell wall structure involves calcium cross-linkage, especially with pectin components. Tissues with low calcium may have weakened cell wall and middle lamella regions. Other possible biological functions of calcium include effects on enzymes and calcium–phytohormones interactions. However, very few enzymes are known to be activated by calcium and in vivo free calcium in the cytoplasm and chloroplasts must be maintained to avoid enzyme inhibition, precipitation of phosphate, and competition with magnesium for binding sites.

Many factors that affect calcium distribution may also influence occurrence of calcium related disorders. These include humidity, root pressure, and phytohormone activity. Low calcium does not always result in development of physiological disorders. In apple, for example, bitter pit incidence during storage can be extremely high in early harvested fruit, but decline to a minimum as fruit reach physiological maturity, even though calcium concentrations in the tissue remain similar. As fruit mature further, the incidence of senescent breakdown during storage can increase. Therefore, the type and severity of the calcium related deficiency can vary greatly according to the maturity of the fruit at harvest, indicating the critical involvement of unknown factors in susceptibility of tissues to injury. However, they are not calcium deficient disorders per se (Watkins 2003).

Therefore, it could be summarized that most information on nutrition and physiological disorders has centered on calcium. In addition to those described for apple, a wide range of disorders associated with calcium deficiency are recognized. Foliar symptoms of calcium deficiency are rarely observed, but disorders of fruits, storage roots, tubers, and compact leafy vegetables have been well described.

6 Integrated Nutrient Management

The chemical fertilizers have played a very significant role in providing nutrients for intensive crop production, which has brought about manifold increase in production of fruit crops. Though the chemical farming helped the farmers to accomplish new strides in horticulture, but their indiscriminate and unscrupulous use in horticulture/agriculture has led to deterioration of soil health. With the increased use of fertilizers in an unbalanced manner, will led to diminishing soil productivity and multiple nutrient deficiencies. The gravity of environmental degradation caused by the faulty cultivation practices had led to focus on ecologically sound, viable and sustainable farming system. One such alternative horticulture system, which will help to overcome the problem of soil degradation and declining soil fertility and crop yield, is integrated nutrient management. Integrated nutrient management envisages the use of chemical fertilizers in conjunction with organic manures, green manures, crop residues, legumes in a cropping system and locally available resources with the objectives of sustaining high yield and ensuring environmental safety. Objectives of INM are to reduce inorganic fertilizer requirement, to restore the organic matter in soil and to increase nutrient use efficiency, to maintain quality in terms of physical, chemical and biological properties of soil, to maintain the nutrient balance between the supplied nutrient and nutrient removed by plant and to improve soil health and productivity on sustainable basis (Kurubar 2007).

A large number of diverse materials can serve as sources of plant nutrients. These can be natural, synthetic, recycled wastes or a range of biological products including microbial inoculants. Except for microbial inoculants (biofertilizers), all of these contain one, two or several plant nutrients in readily or potentially available forms. A certain supply of mineral and organic nutrient sources is present in soils, but these often have to be supplemented with external applications for better plant growth. In practical farming, a vast variety of sources can find use in spite of large differences in their nature, nutrient contents, forms, physicochemical properties and rate of nutrient release. These are not mutually exclusive but can be used together as components of integrated nutrient management (INM). Nutrient sources are generally classified as organic, mineral or biological. Organic nutrient sources are often described as manures, bulky organic manures or organic fertilizers. Most organic nutrient sources, including waste materials, have widely varying composition and often only a low concentration of nutrients, which differ in their availability. Some of these, such as cereal straw, release nutrients only slowly (owing to a wide C:N ratio) while others such as the N-rich leguminous green manures or oilcakes decompose rapidly and release nutrients quickly. The majority of nutrient input to agriculture comes from commercial mineral fertilizers. Organic manures are considered to play a significant but lesser role in nutrient contribution, leaving aside their beneficial effects on soil physico-chemical and biological properties. Such a conclusion could be due in part to inadequate data on the production and consumption of organic sources as compared with mineral fertilizers. Appreciable amounts of nutrients can also be brought in with rain (e.g. atmospheric deposition of nitrate and sulphate) and with irrigation water (Roy et al. 2006).

INM is a well-accepted approach for the sustainable management of soil productivity and increased crop production (Motsara and Roy 2008). The concept of INM aims to increase the efficiency of use of all nutrient sources, be they soil resources, mineral fertilizers, organic manures, recyclable wastes or biofertilizers. Extension staff, who are to translate research data into practical recommendations will need to take stock of both farmers' expertise and the applicability of research results. Available knowledge will need to be summarized competently and evaluated economically in order to provide practical guidelines for the adoption of INM by farmers having a range of investment capacities for achieving food security on a sustained basis. At the same time, plant nutrition research must continue to develop new techniques while refining existing ones based on feedback from the field (Roy et al. 2006).

Finally, the concepts of INM could be concluded as follows:

1. Regulated nutrient supply for optimum crop growth and higher productivity.
2. Improvement and maintenance of soil fertility.
3. Zero adverse impact on agroecosystem quality by balanced fertilization of organic manures, inorganic fertilizers and bio- inoculants.

Therefore, it could be concluded that integrated nutrient management is a well-accepted approach for the sustainable management of soil productivity and increased crop production. Objectives of INM are to reduce inorganic fertilizer requirement, to restore the organic matter in soil and to increase nutrient use efficiency, to maintain quality in terms of physical, chemical and biological properties of soil, to maintain the nutrient balance between the supplied nutrient and nutrient removed by plant and to improve soil health and productivity on sustainable basis.

6.1 Common Mistakes in Nutrient Management

The goals of a good nutrient management program are twofold: to provide sufficient nutrients for crop or animal growth throughout their life cycle, and to minimize negative impacts of nutrient losses on the environment. A good on-farm nutrient management plan would aim to achieve the following goals to improve sustainability:

- Improve or maintain soil fertility.
- Minimize the use of off-farm nutrient inputs, especially synthetic fertilizer, thereby reducing energy used for fertilizer production.
- Ensure efficient use of nutrients, thereby reducing nutrient leaching and runoff and improving water quality.
- Ensure effective use and recycling of on-farm sources of nutrients.

In addition to providing the correct amounts of different nutrients for crop growth, it is equally important to synchronize the availability of the nutrients in the soil to meet the varying crop demands through the growing season. If the nutrient supply is not synchronized with the crop demand, then either the plants suffer nutrient stress (availability too low) or excess nutrients accumulate in the soil and are vulnerable to losses via leaching or as adsorbed nutrients on sediment lost with surface runoff (Crews and Peoples 2005).

Nutrient management plans are comprehensive plans for managing nutrients for crops and animals. Such plans are increasingly required to meet water quality guidelines. Many state extension services have developed tools to help farmers develop their plan. Typically, a plan incorporates some kind of soil testing, use of a budget or credit approach to determine input levels needed for a specified and realistic yield goal, and measurement of nutrient contents for all inputs including manure, composts, and use of other best management practices (BMPs). BMPs vary by regions but can include recommendations for methods and timing of fertility applications, use of specific soil or plant tissue tests, use of conservation buffers, use of cover crops, and use of conservation tillage (NRC 2010).

The implementation of optimal plant nutrition is more difficult than generally assumed. As a result, deviations from the optimal supply frequently occur. In practical agriculture, owing to many uncontrollable variables, perfect implementation of scientific findings is rarely possible. Efficient nutrient management should start by avoiding common mistakes. Some suggestions for avoiding common mistakes in nutrient management are provided below:

- Maintain the soil in good condition as the basis for high NUE. Common mistakes include: overlooking too high or too low soil pH, inadequate organic matter, and poor soil structure.
- Apply adequate nutrients in order to achieve a realistic yield level. A common mistake is to strive for an unrealistic yield level. Where excess N is given for an unrealistic yield, a part of the N remains unutilized and may be lost.
- High yield levels are rarely reached on the basis of own practical experience alone. A common mistake is make insufficient use of available diagnostic techniques.
- Ensure a balanced supply of nutrients taking into account available soil nutrients. A common mistake is the over-application or under-application of some nutrients, e.g. part of NPK remains ineffective where there is S or Zn deficiency, and part of N remains unused where there is P deficiency.

- Check whether nutrients other than NPK, such as Mg, S and micronutrients, should be applied to a crop with high requirements. A common mistake is to overlook hidden hunger, which can limit growth and yield.
- Select the right kind of fertilizer material. A common mistake is the failure to consider the secondary effects of fertilizers, e.g. the S component for increasing the oil content in oil crops and protein content in legumes. In addition, acid forming fertilizers can be used in high pH soils to bring the pH towards optimum and help in mobilizing deficient nutrients such as Mn and Zn.
- Use fertilizers with a low cost per unit of nutrients where they are equally effective. For example, per unit of P, TSP is cheaper than SSP (where S is not a limiting factor) although; TSP is more expensive than SSP on a per-bag basis.
- A common mistake is to cost fertilizers on a per-tonne or per-bag basis.
- Nutrients that benefit more than one crop through residual effects should be evaluated and costed differently to nutrients that do not leave a significant residual effect. A common mistake is to equate N and P in a similar manner in terms of their agro-economic response.
- Fertilizer use should give maximum net returns with a minimum benefit–cost ratio (BCR) of 2:1 – the higher the ratio, the better. A common mistake is consider only the BCR, disregarding the absolute net return (Roy et al. 2006).

The most important determinants of INM could be concluded as follows:

1. Nutrient requirement of cropping system as a whole.
2. Soil fertility status and special management needs to overcome soil problems, if any.
3. Local availability of nutrients resources for example organic, inorganic and biological sources.
4. Economic conditions of farmers and profitability of proposed INM option.
5. Social acceptability.
6. Ecological considerations.
7. Impact on the environment.

Therefore, it could be concluded that the most goals of a good nutrient management program are twofold: to provide sufficient nutrients for crop or animal growth throughout their life cycle, and to minimize negative impacts of nutrient losses on the environment. The most important suggestions for avoiding common mistakes in nutrient management are apply adequate nutrients, ensure a balanced supply of nutrients, and select the right kind of fertilizer material.

6.2 Penetration of Surface-Applied Nutrients into the Root Zone

Fertilizers spread on the soil surface, whether bare soil or with plant cover, will penetrate slowly into the top layer if they are water soluble and if there is sufficient moisture. Dryness after fertilization results in a delay in fertilizer nutrient uptake because the applied nutrient cannot be transported to the roots owing to inadequate moisture. Water-insoluble fertilizers such as PRs or elemental S products need to be mixed into the root zone after application on the surface. The incorporation of insoluble fertilizers applied to grassland is generally left to slow mixing by soil fauna. Because this is a slow process, a good supply of nutrients should be given during seed-bed preparation or at sowing. During the penetration process, fertilizer components of different solubilities in the same product separate. For example, in the case of calcium ammonium nitrate, the $CaCO_3$ remains on the surface much longer than does the easily soluble ammonium nitrate. Once in the soil, the nitrate moves more quickly than does the ammonium. In the case of an NPK complex fertilizer, the N component moves more quickly than the K and much more quickly than the P.

Fertilizer placement is generally made at sowing time or soon after in a number of ways:

- in a band a few centimeters to the side and below the seed;
- in a band directly below the seed, although this may hinder growth of the tap-root;
- in immediate contact with the seed, termed combine drilling (only in moist soils and mainly with phosphate as close contact with N may damage the seed);
- in one or two bands on one or both sides of plant rows;
- by spot application between plants as in the case of USGS between rice hills or as in the case of ring placement around trees (Roy et al. 2006).

Therefore, it could be concluded that fertilizers spread on the soil surface, whether bare soil or with plant cover, will penetrate slowly into the top layer if they are water soluble and if there is sufficient moisture. The most important consideration should be taken into account to fertilizer placement are in a band a few centimeters to the side and below the seed, in a band directly below the seed, in immediate contact with the seed, and in one or two bands on one or both sides of plant rows.

6.3 From Fertilization to Integrated Nutrient Management

Owing to the widespread use of fertilizers containing N, P and K and their effectiveness in increasing crop yields the world over, the term fertilization has become synonymous with the use of commercial NPK fertilizers. This is a rather narrow outdated concept, which does no justice to the wide field of plant nutrition or to the implications concerning undesirable environmental effects. Although fertilizers have benefited from more systematic and well-defined production and marketing, there are other effective sources of plant nutrients. These include crop residues, organic manures, various recyclable wastes and biofertilizers. Farmers all over the world have been using organic manures for a very long time. Diverse nutrient sources can be used in an integrated manner to meet the external nutrient supplies of any cropping system. Towards this end, scientifically, there is no conflict between mineral and organic sources of plant nutrients (Roy et al. 2006).

Although the term fertilization still has a place to describe the actual nutrient supply to crops, it is now gradually being replaced by the wider concept of integrated plant nutrition system (IPNS) or INM. Fertilizers are and will continue to be a major component of INM for producing high yields of good quality on a sustained basis in many parts of the world. The basic concept underlying IPNS/INM is the maintenance or adjustment of soil fertility/productivity and of optimal plant nutrient supply for sustaining the desired level of crop productivity (FAO 1995). The objective is to accomplish this through optimization of the benefits from all possible sources of plant nutrients, including locally available ones, in an integrated manner while ensuring environmental quality. This provides a system of crop nutrition in which plant nutrient needs are met through a pre-planned integrated use of: mineral fertilizers; organic manures/fertilizers (e.g. green manures, recyclable wastes, crop residues, and FYM); and biofertilizers. The appropriate combination of different sources of nutrients varies according to the system of land use and the ecological, social and economic conditions at the local level (Roy et al. 2006).

Therefore, it could be concluded that, although the term fertilization still has a place to describe the actual nutrient supply to crops, it is now gradually being replaced by the wider concept of integrated plant nutrition system (IPNS) or INM. Although fertilizers have benefited from more systematic and well-defined production and marketing, there are other effective sources of plant nutrients.

6.4 The Need for Integrated Nutrient Management

The need to adopt a wider concept of nutrient use beyond but not excluding fertilizers results from several changing circumstances and developments. These are:

- The need for a more rational use of plant nutrients for optimizing crop nutrition by balanced, efficient, yield-targeted, site- and soil-specific nutrient supply.
- A shift mainly from the use of mineral fertilizers to combinations of mineral and organic fertilizers obtained on and off the farm.
- A shift from providing nutrition on the basis of individual crops to optimal use of nutrient sources on a cropping-system or crop-rotation basis.
- A shift from considering mainly direct effects of fertilization (first-year nutrient effects) to long-term direct plus residual effects. To a large extent, this is accomplished also where crop nutrition is on a cropping-system basis rather than on a single-crop basis.
- A shift from static nutrient balances to nutrient flows in nutrient cycles.
- A growing emphasis on monitoring and controlling the unwanted side effects of fertilization and possible adverse consequences for soil health, crop diseases and pollution of water and air.
- A shift from soil fertility management to total soil productivity management. This includes the amelioration of problem soils (acid, alkali, hardpan, etc.) and taking into account the resistance of crops against stresses such as drought, frost, excess salt concentration, toxicity and pollution.
- A shift from exploitation of soil fertility to its improvement, or at least maintenance.
- A shift from the neglect of on-farm and off-farm wastes to their effective utilization through recycling.

These realizations have led to the widening of the concept of fertilization to one of INM, where all aspects of optimal management of plant nutrient sources are integrated into the crop production system. For developing INM practices, the cropping systems rather than an individual crop, and the farming systems rather than the individual field, are the focus of attention. In contrast to organic farming, INM involves a needs-based external input approach, taking into account a holistic view of soil fertility. One of the aims of INM is to obtain high yields and good product quality – in a sustainable agriculture with practically no damaging effects on the environment. INM offers great possibilities for saving resources, protecting the environment and promoting more economical cropping (Roy et al. 2006).

Therefore, it could be concluded that, the need to adopt a wider concept of nutrient use beyond but not excluding fertilizers results from several changing circumstances and developments. The need for a more rational use of plant nutrients for optimizing crop nutrition by balanced, efficient, yield-targeted, site- and soil-specific nutrient supply.

6.5 Components of Integrated Nutrient Management

The concept of INM is that of a nutrient integrator and not one of nutrient excluder. The major components of INM are the well-known and time-tested sources of plant nutrients with or without organic matter. These primarily include:

- mineral fertilizers containing both major nutrients and micronutrients;
- suitable minerals such as phosphate rock (PR), pyrites and elemental S;
- crop residues;
- green manures and green leaf manures;
- various organic manures of plant, animal, human and industrial origin;
- recyclable wastes from various sources with or without processing provided these do not contain harmful substances or pathogens above permissible limits;
- animal slurries and biogas plant slurry;
- microbial inoculants (biofertilizers);
- commercial organic fertilizers (Roy et al. 2006).

It could be summarized the following advantages of INM as follows:

1. Enhances the availability of applied as well as native soil nutrients
2. Synchronizes the nutrient demand of the crop with nutrient supply from native and applied sources.
3. Provides balanced nutrition to crops and minimizes the antagonistic effects resulting from hidden deficiencies and nutrient imbalance.
4. Improves and sustains the physical, chemical and biological functioning of soil.
5. Minimizes the deterioration of soil, water and ecosystem by promoting carbon sequestration, reducing nutrient losses to ground and surface water bodies and to atmosphere.

Therefore, it could be concluded that, the major components of INM are mineral fertilizers containing both major nutrients and micronutrients, phosphate rock, pyrites and elemental S, crop residues, green manures and green leaf manures, various organic manures of plant, animal, human and industrial origin, recyclable wastes and biofertilizers.

6.6 *Nutrient Recovery by Crops and Nutrient Removal*

An assessment of nutrient additions, removals and balances in the agricultural production system yields useful practical information on whether the nutrient status of a soil (or area) is being maintained, built up or depleted. It also gives insights into the level of fertilizer-use efficiency and the extent to which externally added nutrients have been absorbed by the crop and utilized for yield production. It can also forewarn about nutrient deficiencies that may aggravate in the coming years and need attention. Figure 14 provides a simplified depiction of nutrient additions and removals. Most of the arrows in this figure also include nutrient recycling to a varying extent. For example, on the input side, part of mineral fertilizers, particularly N, S and K, can leach down but be recycled to the extent the ground waters are pumped for irrigation. Over a toposequence, the nutrient loss for one field can become the nutrient gain for another field (and farmer). Nutrients from organic manures can enter the plant after mineralization. Atmospheric deposits (N and S) originate from N in the air, gaseous losses and pollution. Similarly, inputs through sedimentation have often been brought in by erosion from higher levels (output) and, in many cases, are actually intersite transfers (30 % of the soil and nutrients moved by water erosion end up in the sea, the remaining 70 % stay on the land). On the output side of Fig. 14, harvested crop parts and crop residues both yield valuable organic manures. Most estimates of nutrient removal by crops (from the soil) are overestimates because nutrient removal is often equated with nutrient uptake. This is not

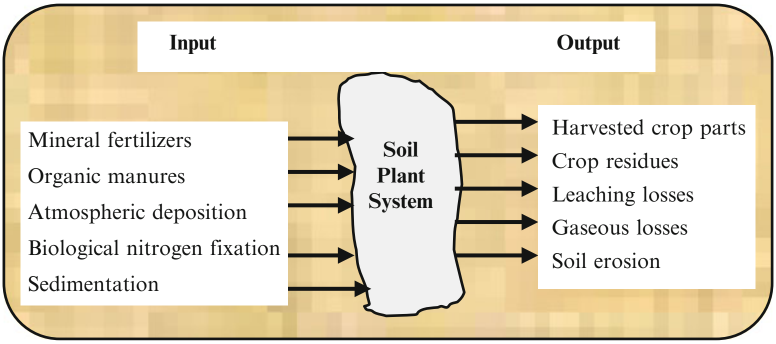

Fig. 14 A simplified depiction of nutrient additions and removals (Adapted from Smaling 1993)

the case in many situations. The proportion of nutrients taken up that constitutes nutrient removal can vary from less than 10 % (as in cardamom) to about one-third (as in coffee) to as much as 90 % as in several field crops when only stubbles and roots are left behind. Estimates of nutrient input and output allow the calculation of nutrient balance sheets both for individual fields and for geographical regions. It is a bookkeeping exercise, similar in many ways to keeping a bank account. The extent of nutrient removals from the soil system can provide useful information for optimizing crop nutrition (Roy et al. 2006).

At harvest time, plants contain considerable amounts of nutrients in plant parts such as grain, straw, stalks, beets, tubers and fruits, but only a small portion is contained in the roots. Depending on which plant parts are harvested and removed, the nutrients contained in them are removed from the field. In many developing countries where grain crops are harvested manually, the entire nutrients present in grain and straw or stover may be removed from the field. In the case of green manure crops, all plant nutrients in the biomass are returned to the soil and no nutrients are removed, except in situations where legume pods are removed for consumption. In fact, net soil enrichment takes place because of the contribution from BNF in case of leguminous green manures. Knowledge of nutrient removal from the field is essential for calculating the amounts of nutrients taken away through harvested crops and for establishing a nutrient balance sheet. The nutrient removal data are more useful where computed on the basis of one basic unit of a harvest, e.g. 1 t of grain or 1 t of straw, so that the total removal at a certain yield level can be calculated easily. Average removal data are useful where nutrients have not been absorbed in excess. Where there is luxury consumption of nutrients, the corresponding removal data can be misleading. In intensive agriculture, N and K data tend to be biased upwards because of this factor. Therefore, larger than necessary amounts may be determined for the replacement of nutrient removals (Fig. 15; Roy et al. 2006).

Plant needs for water and nutrients are interdependent. Water is not only required for the growth of plants but is also the medium through which nutrients are transported to the roots and absorbed by them. A good water supply improves the nutritional status of crops, and an adequate nutrient supply saves water. With properly coordinated management of nutrients and water, the farmer can increase crop productivity substantially through their efficient use. This holds true both for irrigated and rainfed situations. Application of optimal nutrients without access to adequate water results in poor utilization of the applied nutrients. Similarly, application of low doses of nutrients under conditions of adequate water supply results in a waste of the valuable water resource. Water management is inseparable from good nutrient management practices and vice versa.

Soil moisture conditions have major effects on productive processes such as the accessibility, availability, uptake and use of soil nutrients for crop growth and also on negative processes such as creating anaerobic conditions, and losses of nutrients from the soil (Fig. 16).

Therefore, it could be concluded that, the assessment of nutrient additions, removals and balances in the agricultural production system yields useful practical information on whether the nutrient status of a soil is being maintained,

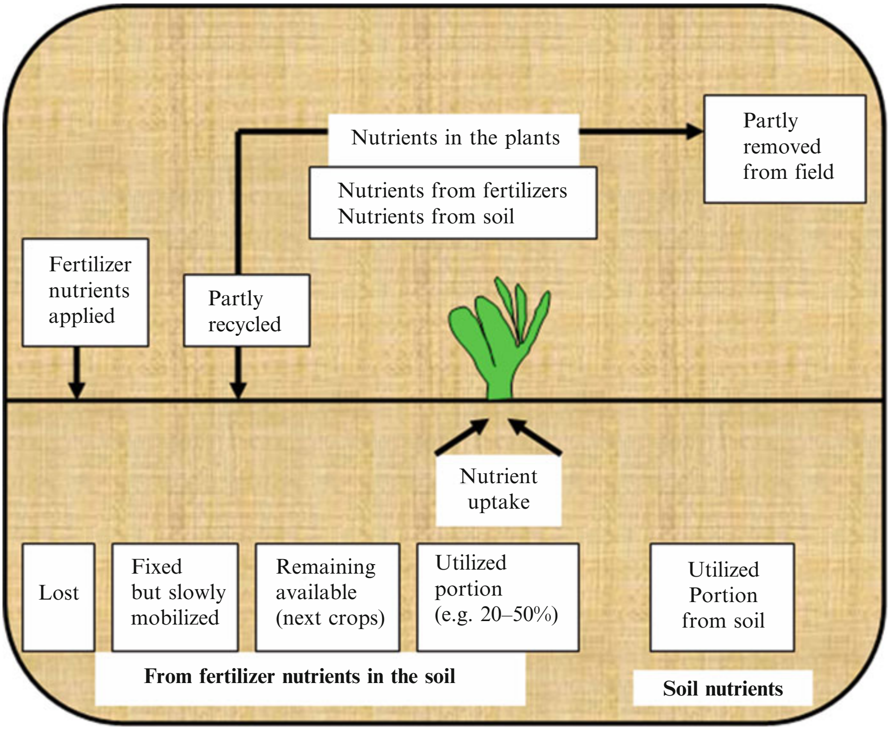

Fig. 15 An illustration of the partial recovery of applied nutrients by crops (Adapted from Finck 2006)

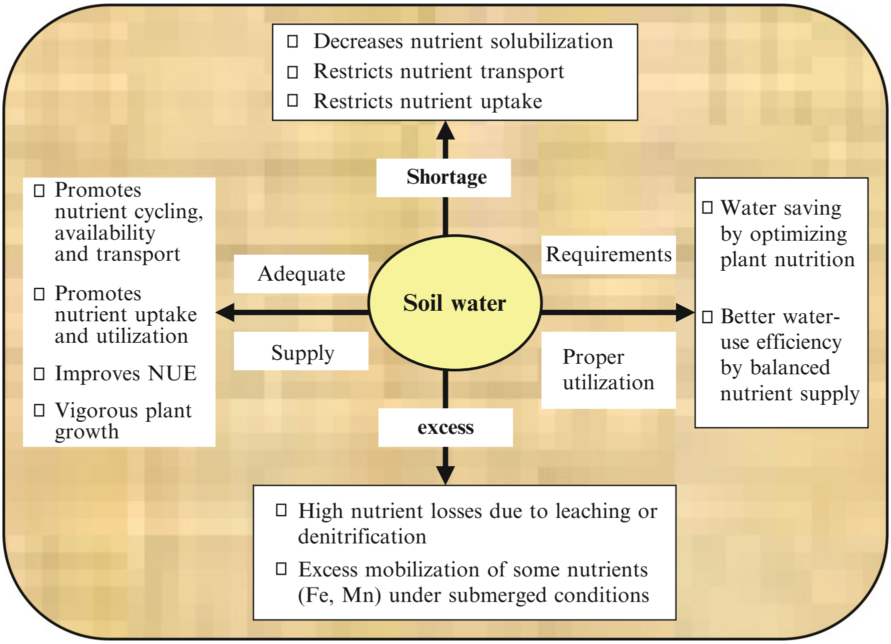

Fig. 16 The influence of soil water status on plant nutrition (Adapted from Finck 2006)

built up or depleted. It also gives insights into the level of fertilizer-use efficiency and the extent to which externally added nutrients have been absorbed by the crop and utilized for yield production.

7 Conservation Agriculture for Improving Soil Quality and Agroecosystem

It is well known that long before the Greek or Roman Empires rose to prominence, the Egyptians developed an organized civilization around the Nile River that lasted from about 3300 BC to 332 BC. The Egyptian civilization was based on irrigation and the fertility of their agricultural soils was naturally maintained through frequent flooding of the Nile River, which led to deposition of rich silt. The Egyptians had a cultivated agriculture and they understood preparing soil before sowing. They also understood that the Nile floods watered and fertilized the soils and the floods removed accumulations of salts. The Phoenicians, who were at their height from about 1200–800 BC, were the first to construct bench terraces on steep slopes in Lebanon and Syria. They practiced a cultivated, irrigated agriculture on these terraces, which showed an understanding of soil management to prevent erosion and thus allow for successful cropping. Another early Mediterranean civilization was based out of the city of Carthage in Tunisia. Eventually conquered by the Romans, the Carthaginians were excellent farmers with advanced cultivation and irrigation systems. However, erosion by wind and water eventually removed the topsoil around Carthage, and today the region cannot support the populations it once did (Brevik and Hartemink, 2010).

It is well established that agriculture can be defined as an industry where products are produced using the activities of organisms such as crops and livestock. Modern agriculture has chosen to rely on fossil energy as the primary means to stimulate the activities of these organisms. Is it possible to replace current technologies based on fossil energy with proper interactions operating between crops/livestock and other organisms to enhance agricultural production? If the answer is yes, then modern agriculture, which uses only the simplest biotic responses, can be transformed into an alternative system of agriculture, in which the use of complex biotic interactions becomes the key technology.

The aim of modern agriculture can be characterized as an optimization problem in a low dimensional space, where each species represents one dimension of the space, and production is being optimized. Optimization in a low dimensional space is expected to be easier to accomplish than optimization in a higher dimensional space because we can more easily rely on our intuition in a low dimensional space. Because an agricultural system that relies on complex biotic interactions is expected to have more species that are functionally important in production than does the current system, it will be necessary to optimize agricultural production and to minimize adverse environmental effects in a multidimensional space. This will be no easy task. However, many agricultural researchers, especially those who take a comprehensive view of agricultural systems, believe that development of such a system is the key to harmonizing improvements in agricultural production and preservation of the environment. In the future, much more complex interactions operating in agroecosystems will certainly be revealed, and their structures and functions will be elucidated for use in agriculture (Shiyomi and Koizumi 2001).

The basic principle of conservation agriculture is to minimize soil-disturbance in order to stabilize soil structure, increase fertility and balance the ecosystem. Applied together, conservation agriculture practices – no tillage, permanent soil cover, use of cover crops and crop rotations – have complementary positive outcomes: no tillage maintains stable soil structure and biological activity; a permanent organic soil cover protects the soil surface from erosion and creates a stable and favorable microclimate; cover crops provide organic matter, reduce erosion and improve soil fertility; and crop rotation enhances the biodiversity of the system and therefore contributes to weed, pest and disease control. Conservation agriculture is a model of sustainable agriculture as it leads to profitable food production while protecting and even restoring natural resources. Conservation agriculture benefits farmers because it reduces production costs and increases yields, but it also has positive impacts on the whole society: enhancement of food security thanks to a better soil fertility, improvement of water quality, reduction of erosion and mitigation of climate change by increasing carbon sequestration, etc. Conservation agriculture systems are also less sensitive to extreme climatic events and therefore contribute to the adaptation to climate change and the resilience of agricultural systems. Hence, conservation agriculture becomes a fundamental element of sustainable production intensification, combining high production with the provision of environmental services (Berger et al. 2009).

Agroecosystems or agricultural systems are ecological systems modified by human beings to produce food, fibre or other agricultural products. Like the ecological systems they replace, agroecosystems are often structurally and dynamically complex but their complexity arises primarily from the interaction between socioeconomic and ecological processes (Conway 2008). In recent years, agroecology has increasingly become a topic of global interest and concern. This rise in popularity is due to the need to respond to the diverse challenges facing agriculture such as sustainable production, food security, climate change, conservation of biodiversity in agroecosystems, and rural development. These challenges involve global and systems aspects and cannot be attacked using only disciplinary approaches. Hence, agroecology as a scientific discipline might be particularly suited, because interdisciplinary and systems approaches are major foundations of many present agroecology interpretations. However, to understand the issue better, we must start from the beginning; the origins of agroecology. Since the first use of the term '*agroecology*' in the early twentieth century, its meanings, definitions, interpretations and approaches have changed enormously up to the present (Wezel and Jauneau 2011).

Soil scientists have the know-how to make a desert bloom. Important technological innovations that can achieve this include no-till farming with residue mulch and cover crops, judicious use of fertilizers and integrated nutrient managements, precision farming to meet soil-specific needs, water harvesting and recycling along with drip irrigation/fertigation, retiring marginal lands for nature conservancy and restoring wetlands, and using integrated watershed management approaches to improve water resources. In addition to adopting strategies of sustainable management of soil and water resources, use of integrated pest management in conjunction with biotechnology and transgenic plants are also critical to transforming traditional agriculture in developing countries. Indeed, the appropriate use of biotechnology can facilitate the development of new genotypes with high productive potential under biotic and abiotic stresses. So, working with nature in developing plants that can better withstand biotic and abiotic stresses is appropriate, beneficial, and in accord with natural processes (Lal 2009e).

It is worth to mention that tillage-based soil management for intensive crop production generally leads to soil degradation and eventual loss of crop productivity. Moreover, farmers have to face high costs for fuel, labor, agro-chemicals, and other production inputs required by intensive cropping. Intensive tillage causes a greater loss of soil carbon and increases greenhouse gas emission, mainly CO_2, that not only impacts soil productive capacity but also impacts atmospheric quality that is responsible for climate change. The following major points have been found to be associated with the adoption of conservation agriculture when compared with tillage-based agriculture:

- Improved soil structure and stability;
- Increased drainage and water-holding capacity;
- Reduced risk of rainfall runoff and pollution of surface waters with pesticides of up to 100 % and fertilizers up to 70 %;
- About one quarter to one half lower energy consumption and lower CO_2 emissions (Fig. 17 and Table 20).

Moreover, crop residues are more naturally left on the surface to protect the soil and to drive the carbon cycle towards the conversion of plant biomass carbon to soil organic matter and humus. The changes in the physical environment affect many different groups of organisms, and although there is a wide range of responses among different species, most organism groups are in greater abundance in conservation agriculture than in tillage-based systems. The practice of conservation agriculture requires attention to crop rotation, adequate weed control, management of crop residues, mulching, introduction and management of cover crops, changes in seeding, and transplanting equipment. Despite the benefits linked to the practice of conservation agriculture, there is still much skepticism – especially in Europe – about the suitability of the conservation practice within the European soil and climatic conditions and cropping systems. Nevertheless, it will be more necessary than ever for farmers to adopt sustainable agricultural systems that can simultaneously meet their economic needs, address the concerns of consumers, and minimize the impact on the environment (Stagnari et al. 2009).

It is estimated that of the 77 % of the world's total cropland area that is affected by water erosion (837 out of 1,094 Mha), 83 % of the land prone to wind erosion (457 out of 548 Mha), 97 % of that subject to nutrient mining (132 out of 136 Mha), 94 % affected by salinization (72 out of 77 Mha), and 83 % of that prone to acidification (5 out of 6 Mha), occur in developing countries. These are also the regions

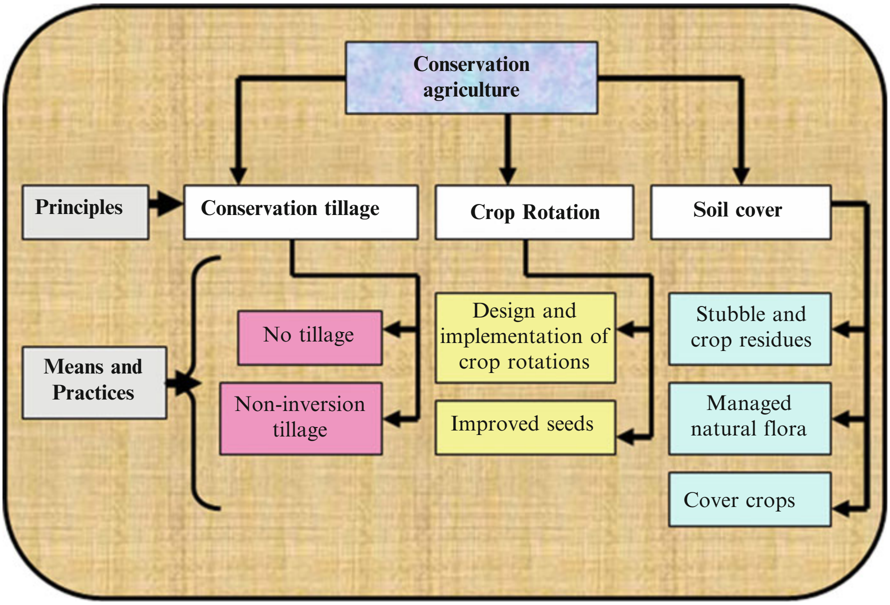

Fig. 17 The three principles of conservation agriculture and the main practices and means needed to achieve each principle (Adapted from Stagnari et al. 2009)

Table 20 Benefits and costs associated with conservation agriculture

Advantages	Drawbacks
Reduction in on-farm costs: savings of time, labor, fuel, and machinery	Purchase of specialized planting equipment
Increase in soil fertility and moisture retention, resulting in long-term yield increase, decreasing yield variations, and greater food security	Short-term pest problems due to the change in crop management
Stabilization of soil and protection from erosion leading to reduced downstream sedimentation	Acquiring of new management skills
Reduction in toxic contamination of surface water and groundwater	Application of additional herbicides
More regular river flows, reduced flooding, and the re-emergence of dried wells	Formation and operation of farmers' groups
Recharge of aquifers as a result of better infiltration	High perceived risk to farmers because of technological uncertainty
Reduction in air pollution resulting from soil tillage machinery	Development of appropriate technical packages and training programs
Reduction of CO_2 emissions into the atmosphere (carbon sequestration)	
Conservation of terrestrial and soil-based biodiversity	

Adapted from Stagnari et al. (2009)

where 99 % of the projected increase in world population is expected to occur. Furthermore, farming communities in developing countries consist of resource-poor and small-size (<2 ha) landholders who use extractive farming practices involving little or no off-farm input. Therefore, degradation induced decline in soil quality has drastic adverse effects on crop yields and agronomic productivity.

Fertilizers and other soil amendments are neither available to the resource-poor farmers nor are they sure of their effectiveness. Soil quality strongly impacts agronomic productivity, use efficiency of input, and global food security. The significance of dependence of food security on soil quality is likely to increase with decrease in per capita land area, increase in extent and severity of soil degradation, and the projected global warming. Global warming attributed to atmospheric enrichment of CO_2 and other greenhouse gases due to anthropogenic activities such as fossil fuel combustion and land use conversion can exacerbate the problems of soil degradation. The projected increase in temperatures and the frequency of extreme events may accentuate the soil erosion risks because of a decline in soil structure and an increase in erosivity by rainfall and wind. Decline in soil structure is attributed to reduction in soil organic matter content and the decline in stability of aggregates (Lal and Stewart 2010a).

Nowadays, people have come to understand that agriculture should not only be high yielding, but also sustainable (Reynolds and Borlaug 2006). Farmers concerned about the environmental sustainability of their crop production systems combined with ever-increasing production costs have begun to adopt and adapt improved system management practices that lead to the ultimate vision of sustainable agriculture. Conservation agriculture has been proposed as a widely adapted set of management principles that can assure more sustainable agricultural production. The name conservation agriculture has been used to distinguish this more sustainable agriculture from the narrowly defined "conservation tillage" (Wall 2007). Conservation tillage is a widely used terminology to denote soil management systems that result in at least 30 % of the soil surface being covered with crop residues after seeding of the subsequent crop. To achieve this level of ground cover, conservation tillage normally involves some degree of tillage reduction and the use of non-inversion tillage methods. Conservation agriculture removes the emphasis from the tillage component alone and addresses a more enhanced concept of the complete agricultural system. It combines the following basic principles:

1. *Reduction in tillage*: The objective is to achieve zero tillage, but the system may involve controlled tillage seeding systems that normally do not disturb more than 20–25 % of the soil surface.
2. *Retention of adequate levels of crop residues and soil surface cover*: The objective is the retention of sufficient residue on the soil to protect the soil from water and wind erosion; to reduce water runoff and evaporation; to improve water productivity and to enhance soil physical, chemical, and biological properties associated with long-term sustainable productivity. The amount of residues necessary to achieve these ends will vary depending on the biophysical conditions and cropping system.

3. *Use of crop rotations*: The objective is to use diversified crop rotations to help moderate/mitigate possible weed, disease, and pest problems; to utilize the beneficial effects of some crops on soil conditions and on the productivity of subsequent crops; and to provide farmers with economically viable cropping options that minimize risk (Verhulst et al. 2010).

These conservation agriculture principles are applicable to a wide range of crop production systems from low-yielding, dry, rainfed conditions to high-yielding, irrigated conditions. However, the techniques to apply the principles of conservation agriculture will be very different in different situations, and will vary with biophysical and system management conditions and farmer circumstances. Applying conservation agriculture essentially means altering literally generations of traditional farming practices and implement use. As such, the movement toward conservation agriculture-based technologies normally consists of a sequence of stepwise changes in cropping system management to improve productivity and sustainability. Because of the multifaceted nature of conservation agriculture technology development and extension, activities should be concentrated in a few defined locations representative of certain farming systems rather than have lower intensity efforts on a wide scale. Through the research and training, regional conservation agriculture networks are established to facilitate and foment research and the extension of innovation systems and technologies. The hubs are directly linked to the strategic science platforms operated by international centers and national research institutes to permit the synthesis and global understanding of conservation agriculture, and its adaptability to different environments, cropping systems, and farmers' circumstances (Verhulst et al. 2010).

When evaluating an agricultural management system for sustainability, the central question is: Which production system will not exhaust the resource base, will optimize soil conditions, and will reduce food production vulnerability while at the same time maintaining or enhancing productivity? Soil quality can be seen as a conceptual translation of the sustainability concept toward soil. Within the framework of agricultural production, high soil quality equates to the ability of the soil to maintain a high productivity without significant soil or environmental degradation. Evaluation of soil quality is based on physical, chemical, and biological characteristics of the soil. With respect to biological soil quality, a high quality soil can be considered a "healthy" soil. A healthy soil is defined as a stable system with high levels of biological diversity and activity, internal nutrient cycling, and resilience to disturbance (Rapport 1995). Management factors that can modify soil quality include tillage and residue management systems, as well as the presence and conformation of crop rotations (Karlen et al. 1992). Changes in soil quality are not only associated with management, but also with the environmental context, such as temperature and precipitation (Andrews et al. 2004).

A comparative soil quality evaluation is one in which the performance of the system is determined in relation to alternatives. The biotic and abiotic soil system attributes of alternative systems are compared at some time. A decision about the relative sustainability of each system is made based on the difference in magnitude of the measured parameters. A comparative assessment is useful for determining differences in soil attributes among management practices that have been in place for a certain period (Wienhold et al. 2004). In a dynamic assessment approach, the dynamics of the system form a meter for its sustainability. A dynamic assessment is necessary for determining the direction and magnitude of change a management practice is having (Wienhold et al. 2004), especially when compared to the common, existing farmer practices and it must be understood that this assessment normally must involve an adequate time frame (Verhulst et al. 2010).

Conservation agriculture induces important shifts in soil fauna and flora communities. The different taxonomic mesofauna groups respond differently to tillage disturbance and changed residue management strategies. However, in general tillage, through direct physical disruption as well as habitat destruction, strongly reduces macrofauna including both litter transformers and ecosystem engineers. When reduced tillage is combined with residue retained on the soil surface, this provides residue-borne pathogens and beneficial soil microflora species with substrates for growth, and pathogens are at the soil surface, where spore release may occur. This can induce major shifts in disease pressure in conservation agriculture systems. However, in general, the combination of crop residue retention with reduced tillage also results in an increased functional and species diversity. Functional diversity and redundancy, which refers to a reserve pool of quiescent organisms or a community with vast inter-specific overlaps and trait plasticity, are signs of increased soil health, and allow an ecosystem to maintain a stable soil function. Larger microbial biomass and greater microbial activity, as supported by conservation agriculture, can result in soils exhibiting suppression toward soil-borne pathogens and increased possibilities of integrated pest control are created. The needed yield increases, production stability, reduced risks, and environmental sustainability can only be achieved through management practices that result in an increased soil quality in combination with improved crop varieties. The evidence outlined above for improved soil quality and production sustainability with well implemented conservation agriculture systems is clear, although research remains inconclusive on some points. At the same time, evidence for the degradation caused by tillage systems is convincing especially in tropical and subtropical conditions and for biological and physical soil quality. Therefore, even though we do not know how to manage functional conservation agriculture systems under all conditions, the underlying principles of conservation agriculture should provide the foundation upon which the development of new practices is based, rather than be considered a parallel option to mainstream research activities that focus on improving the current tillage-based production systems (Verhulst et al. 2010).

Therefore, it could be concluded that, it is well established that agriculture can be defined as an industry where products are produced using the activities of organisms such as crops and livestock. Conservation agriculture induces important shifts in soil fauna and flora communities. Agroecosystems or agricultural systems are ecological systems modified by human beings to produce food, fibre or other agricultural products. Before the Greek or Roman Empires rose to prominence, the Egyptians developed an organized civilization around the Nile River that lasted from about 3300 BC to 332 BC. The Egyptian civilization was based on irrigation and the fertility of their agricultural soils was naturally maintained through frequent flooding of the Nile River, which led to deposition of rich silt.

8 Managing Soils for Addressing Global Issues of the Twenty-First Century

Soil science academy is at the crossroads. Its role in ushering the Green Revolution and improving global food production is a success story. It now needs to position itself to effectively address emerging issues of the twenty-first century also, including food security, climate change, water scarcity, waste disposal, energy demand, biodiversity, and more. Judicious management of soils, involving soil quality restoration and improvement in its resilience, is essential to addressing global issues of the twenty-first century. To do so, soil scientists must build bridges across disciplines and develop interdisciplinary programs in close cooperation with climatologists, biologists, ecologist, engineers, economists, social scientists, and policymakers. Undergraduate and graduate curricula must be revised to provide students the necessary background in these disciplines. There is a strong need to develop new and innovative practices based on use of nanotechnology, biotechnology, and information technology. There is a strong need to raise the profile of the soil science profession by creating awareness about its contributions to advancing world food security and meeting emerging needs of the rapidly industrializing society. Soil scientists must be proactive in expressing their views and strengthen channels of communication with public at large, the policymakers, and all stakeholders (e.g., industry). Getting the views of soil scientists heard and acted on is essential to addressing global issues, while promoting political stability and advancing world peace and harmony. It is important that soil scientists publish their findings in high-profile journals and establish strong linkage with industry stakeholders and policymakers. By addressing global issues and societal needs, soil science has a bright and promising future for generations to come (Lal 2010).

Emerging issues of the twenty-first century with ever increasing demands on world soils are outlined below. The concept of '***emerging issues***' is subjective. It is used in here to describe issues that are recognized as very important by the scientific community, but are not yet receiving adequate attention from the policy community. Definitions of '***very important***' and '***adequate***' are left open to those identifying the issues. Emerging issues are further defined as those that are: (1) Critical to the global environment. The issue can be either positive or negative but must be environmental in nature, or environmentally-related. (2) Given priority over the next 1–3 years in the work program of UNEP and, or, other UN institutions and, or, other international institutions concerned with the global environment. (3) Have a large spatial scale. Issues should either be global, continental or 'universal' in nature (by 'universal' we mean an issue occurring in many places around the world). (4) Recognized as '***emerging***' based on newness, which can be the result of: new scientific knowledge;

new scales or accelerated rates of impact; heightened level of awareness; and, or, new ways to respond to the issue. The UNEP Foresight Process has been designed so as to encourage the creative thinking of participants and to be inclusive at the same time (UNEP 2002).

The output of the UNEP Foresight Process is a ranked list of 21 emerging issues described in a way that reflects their linkages to the various dimensions of sustainable development. The issues relate to the major themes of the global environment, as well as important cross-cutting issues. It could be listed these issues according to the different clusters rather than their ranking as follows in Table 21.

On the other hand, Lal (2010) reported that the emerging issues of the twenty-first century with ever increasing demands on world soils could be concluded as follows:

1. Energy consumption
2. Climate change
3. Agricultural land area
4. Soil degradation and desertification
5. Urbanization
6. Water use
7. Fertilizers and agricultural chemicals
8. Food security
9. Waste disposal
10. Industrial raw material

The objective is to enhance soil resilience and its capacity to recover and restore essential processes which moderate ecosystems services and functions by eliminating extractive farming and soil mining. Soil and ecosystem resilience can be enhanced through creation of positive C and elemental budgets, conserving and harvesting/recycling water, afforestation and enhancement of vegetation cover, C sequestration in soil and biota, and using technologies which adapt to current and future changing climate (Lal 2010).

8.1 *Soil Processes and Properties*

There is a strong need for a paradigm shift in our approach to managing soil resources. Table 22 outlines basic characteristics of soil resources and appropriate action plans which may increase soil quality while enhancing net primary productivity and use efficiency of inputs (Lal 2009a, b, c). The strategy is to use modern innovations because problems of the twenty-first century cannot be addressed by technologies developed during the Middle Ages (as is the case in South Asia an SSA). Issues of the twenty-first century must be tackled by modern technologies. Table 23 outlines basic processes which govern soil degradation and lists examples of innovative soil management options to reverse the degradation trends (Lal 2009a, b, c). Un-sustainability and soil degradation can be mitigated only when there are positive C and nutrient budgets in managed ecosystems. Site-specific technologies must be developed by understanding the coupled cycling of C, N, and water. The larger the nutrient and C deficits and longer the mining, the more difficult it is to restore soils and reverse the degradation. The response time of soil to restorative measures also depends on the duration of mismanagement. To some extent the

Table 21 The 21 emerging issues according to UNEP (2002)

Issue ID	Issue title	Ranking[a]
	I. Cross-cutting issues	
001	Aligning Governance to the Challenges of Global Sustainability	1
002	Transforming Human Capabilities for the 21st Century: Meeting Global Environmental Challenges and Moving Towards a Green Economy	2
003	Broken Bridges: Reconnecting Science and Policy	4
004	Social Tipping Points? Catalyzing Rapid and Transformative Changes in Human Behaviour towards the Environment	5
005	New Concepts for Coping with Creeping Changes and Imminent Thresholds	18
006	Coping with Migration Caused by New Aspects of Environmental Change	20
	II. Food, Biodiversity and Land Issues	
007	New Challenges for Ensuring Food Safety and Food Security for 9 Billion People	3
008	Beyond Conservation: Integrating Biodiversity across the Environmental and Economic Agendas	**7**
009	Boosting Urban Sustainability and Resilience	11
010	The New Rush for Land: Responding to New National and International Pressures	12
	III. Freshwaters and Marine Issues	
011	New Insights on Water-Land Interactions: Shift in the Management Paradigm	6
012	Shortcutting the Degradation of Inland Waters in Developing Countries	15
013	Potential Collapse of Oceanic Systems Requires Integrated Ocean Governance	13
014	Coastal Ecosystems: Addressing Increasing Pressures with Adaptive Governance	19
	IV. Climate Change Issues	
015	New Challenges for Climate Change Mitigation and Adaptation: Managing the Unintended Consequences	**7**
016	Acting on the Signal of Climate Change in the Changing Frequency of Extreme Events	16
017	Managing the Impacts of Glacier Retreat	21
	V. Energy, Technology, and Waste Issues	
018	Accelerating the Implementation of Environmentally-Friendly Renewable Energy Systems	**7**
019	Greater Risk than Necessary? The Need for a New Approach for Minimizing Risks of Novel Technologies and Chemicals	10
020	Changing the Face of Waste: Solving the Impending Scarcity of Strategic Minerals and Avoiding Electronic Waste	14
021	The Environmental Consequences of Decommissioning Nuclear Reactors	17

[a] Ranking based on scoring by the UNEP Foresight Panel and after considering the polling results of more than 400 scientists worldwide

Table 22 Soil attributes and their management

Soil attributes	Management strategies
Low water holding capacity	Use zeolites, biosolids, and soil conditioners
Low soil fertility	Use nanoenhanced slow release fertilizers, INM, and precision farming
High susceptibility to erosion	Provide continuous soil cover, use no-till and mulch farming with cover crops, establish contour hedges
Vulnerability to compaction	Avoid heavy traffic when soil is wet, use guided traffic, and promote spoil fauna (earthworms)
Low soil organic matter content	Recycle biosolids, use forages and deep-rotted cover crops, apply biochar, minimize tillage, and control erosion
Low use efficiency of inputs	Deliver water and nutrients directly to plant roots, and eliminate losses
Low productivity	Combine high tech varieties with innovative management options
Susceptibility to biotic and abiotic stresses	Develop varieties which emit molecular-based signals detectable through remote sensing followed by targets intervention

Adapted from Lal (2010)

Table 23 Soil degradation processes and their mitigation

Process	Mitigation
Soil degradation by physical, chemical, and biological process	Address social, economic, and political causes
Low productivity and poor farm income	Adopt modern technologies and compensate farmers for ecosystem services (e.g., trading C)
Severe depletion of nutrient and soil organic matter	Must create positive C and nutrient budgets, including micronutrients
Salinity and waterlogging	Improve drainage, use subdrip irrigation
Traditional vs. modern technologies	Build on traditional knowledge but must use modern technologies
Biofuels and organic farming	Identify specific niches where these may be economically feasible
Vulnerability to desertification	Do not take soils for granted

Adapted from Lal (2010)

carrying capacity depends on the land use and management within the context of climatic factors and socio-economic settings. Soil degradation processes are set in motion when the rate of removal of nutrients and C from soils exceeds the rates of input, as has been the case in SSA since 1950s (Anonymous 2006).

8.2 Biofuels

The growing emphasis on biofuels cannot be ignored by soil scientists. The energy use from modern biofuels (bioethanol, biodiesel, and biogas) of 6–7 EJ/year (1.3–1.5 % of the global energy use) is expected to increase drastically by 2020 and beyond.

Global production of modern biofuels in 2008, estimated at 65 billion liters for bioethanol and 13 million megagrams for biodiesel, is increasing. Producing these biofuels involved use of 6 % of the world's grains and 9 % of Vegetable oil production in 2008. In accordance with the global trends, ethanol production (billion liters) is also increasing steadily in USA from 3.8 in 1992, 7.5 in 2002, 25 in 2007, 34 in 2008, 40 in 2009, and 57 in 2010. Crops suitable for bioethanol are corn (3,500 L ha^{-1}), sugarcane (6,000 L ha^{-1}), sugar beet (7,000 L ha^{-1}), and cassava (4,000 L ha^{-1}). Similarly, crops suitable for biodiesel are oil palm (5,500 L ha^{-1}), rapeseed (1,200 L ha^{-1}), and soybean (400 L ha^{-1}). However, these grain and oil crops are needed to feed the growing human population. Diverting grains for ethanol production caused increase in food prices in 2008. Furthermore, crop residues and animal manure are needed for improving soil quality and sequestrating C. Establishment of biofuel plantations e.g., short-rotation woody perennials and warm season grasses requires additional land, water, and nutrients, which are in short supply and needed for other competing uses. Establishing algal and cyanobacterial farms, next to a source of CO_2 and municipal waste water, is a niche worth exploring. Halophytes can also be grown on salinized soils by irrigation with brackish water (Lal 2010).

8.3 Dialogue with Policy Makers

Soil scientists must make their voices heard by stating loudly and clearly that "*there is no such thing as free biofuels from using crop residues*." There is a heavy price to pay for removal of crop residues for producing cellulosic ethanol in terms of decline in quality of soil and water resources, additional water and nutrients needed, and decline in crop yields. It must also be made clear that additional land, water, and nutrients needed for establishing energy plantations are required for feeding the growing population. Furthermore, it is not possible to produce 4–5 billion megagrams of dry cellulosic feedstock globally by establishing fast growing plantations on marginal or degraded soils. That is a myth not supported by basic principles of soil science. Therefore, soil scientists must advise policymakers to:

- Adopt energy saving options which can reduce energy demand by 25–40 %,
- Restore degraded soils by enhancing resilience, and make these ecoregions as C sink through negative emissions,
- Adopt modern innovations on soils of the managed ecosystems e.g., crop lands, grazing lands, and plantations, and enhance production by adopting land-saving technologies through agricultural intensification, and
- Identify non-C fuel sources e.g., H_2 from biomass or water to take effect by 2030 or 2050 (Lal 2010).

The global average per capita arable land area is rapidly shrinking because of the increase in world population and the conversion of land to urban and industrial uses along with the problem of soil degradation. Therefore, agricultural production must be increased by enhancing productivity per unit area, time, and input. Such an increase in productivity is especially needed in regions where agronomic yields are low because of the widespread use of extractive farming practices e.g., sub-Saharan Africa, South Asia. These are also the regions where soil resources are under great stress, small landholders are severely constrained by the lack of resources needed for investment in soil restoration and purchase of input, institutional support is weak, and infrastructure including access to market is poor (Lal 2010).

Therefore, it could be concluded that, soil science academy is at the crossroads and its role in ushering the Green Revolution and improving global food production is a success story. It now needs to position itself to effectively address emerging issues of the twenty-first century also, including food security, climate changes, water scarcity, waste disposal, energy demand, biodiversity, and more. Judicious management of soils, involving soil quality restoration and improvement in its resilience, is essential to addressing global issues of the twenty-first century. To do so, soil scientists must build bridges across disciplines and develop interdisciplinary programs in close cooperation with climatologists, biologists, ecologist, engineers, economists, social scientists, and policymakers.

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Intercropping Taro and Bambara Groundnut

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Abstract Intercropping involves the cultivation of two or more crops on the same field in both space and time. It is a farming practice that has existed throughout history and one which mimics natural diversity. Intercropping has several advantages over monocropping which include improved resource utilization of light, water and nutrients, as well as yield stability over time. It is a practice that historically contributed towards food security within communities. It offers a sustainable alternative to the more widely practiced monocropping. However, it has been widely regarded as a primitive practice and this has created a scenario whereby there was scant research done on intercropping.

Intercropping as a practice bears huge similarity with neglected crops. Neglected crops too have been regarded as “traditional” crops and have been neglected by researchers, farmers and communities. Despite that they represent a rich biodiversity which has now been lost. Additionally, similar to intercropping, neglected crops have played a historical role of food security and nutritious diets for people. In KwaZulu-Natal, South Africa, taro (*Colocasia esculenta* L. Schott) and bambara (*Vigna subterranea* L. Verdc) landraces represent neglected underutilised crops. Taro has improved in status due to recently improved access to markets. On the other hand, bambara groundnut, despite being highly nutritious, has lost its popularity amongst rural farmers of KwaZulu-Natal, South Africa.

Intercropping taro and bambara groundnut allows farmers to mimic historical diversity that existed in traditional agroecosystems. This study aimed at evaluating productivity of a taro-bambara intercrop under rainfed conditions. Field trials were planted over two summer seasons, 2010/2011 and 2011/2012, in the rural areas of KwaZulu-Natal. Treatments included taro and bambara sole crops as well as 1:1

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(taro: bambara) and 1:2 intercrops. Growth and yield parameters were determined separately for each crop. Thereafter, land equivalent ratio (LER) was calculated to evaluate productivity of the intercrop. Plant height of taro, as the main crop, showed no significant increase or decrease in response to intercropping. Intercropping taro reduced leaf number. Increasing the proportion of bambara in the intercrop combinations lowered leaf number of taro in the 1:2 intercrop relative to the 1:1 intercrop. However, bambara groundnut growth was favoured by intercropping. Bambara groundnut plants were taller and had more leaves under intercropping. Yield was lower under intercropping. We showed that, compared with the added benefit of having a second crop, the extent of such reduction in taro and bambara yields were negligible. Furthermore, LER showed that intercropping taro was more productive than sole cropping. On average, for both seasons, the 1:1 intercrop had a LER of 1.53 compared with 1.23 for the 1:2 intercrop. It is concluded that intercropping taro and bambara at a ratio of 1:1 is feasible and productive under rainfed conditions.

Keywords Bambara • Intercropping • Landraces • LER • Taro

1 Introduction

The water-energy-food security nexus continues to dominate debates about world economic development in response to modern challenges. This debate has to take place in the context of the need to conserve biodiversity. The combination of predicted climate change and increasing population growth has painted a gloomy picture of future food security for countries like South Africa that already have scarce water resources (RSA 1998). The impending threat has led to previously neglected and underutilised species/crops (NUS) being touted as possible future crops. However, decades of 'neglect' by researchers, farmers and policy makers in favour of major crops have meant that there currently exists limited information describing agronomy and water-use of NUS. There has now been renewed effort to study these crops; however, these efforts have been mimicking the approaches used to study the major crops (Mabhaudhi 2009). There is a need to study NUS within the context of the traditional cropping systems in which they were preserved such as intercropping. Here we looked at the case of the two NUS – bambara groundnut and taro landraces. Figures 1 and 2 show some landraces of taro and bambara groundnut common in KwaZulu-Natal province of South Africa.

A growing niche market for organically produced eddoe type taro (*Colocasia esculenta* L. Schott) has recently emerged in South Africa (Modi 2003). This has resulted in an increase in taro production, in terms of area of land under cultivation and numbers of subsistence farmers cultivating it in pure stands. Most of these farmers are women, who now depend on the income received from marketing the crop to retail chains as a source of livelihood (Eybers 2008). However, increased taro cultivation, as a sole crop (Fig. 3), has led to a possible loss in species diversity,

Fig. 1 Two taro landrace varieties from KwaZulu-Natal: (**a**) Var. *esculenta* – dasheen with one main corm and a *huli* used as planting material and, (**b**) Var. *antiquorum* – eddoe with numerous side cormels. The eddoe type which is more widely cultivated was used in this study

Fig. 2 Different seed colours occurring in local bambara groundnut landraces; (**a**) *Light-brown*, (**b**) *Red*, (**c**) *Brown*, and (**d**) *Black*. The '*Red*' landrace was used in this study (Color figure online)

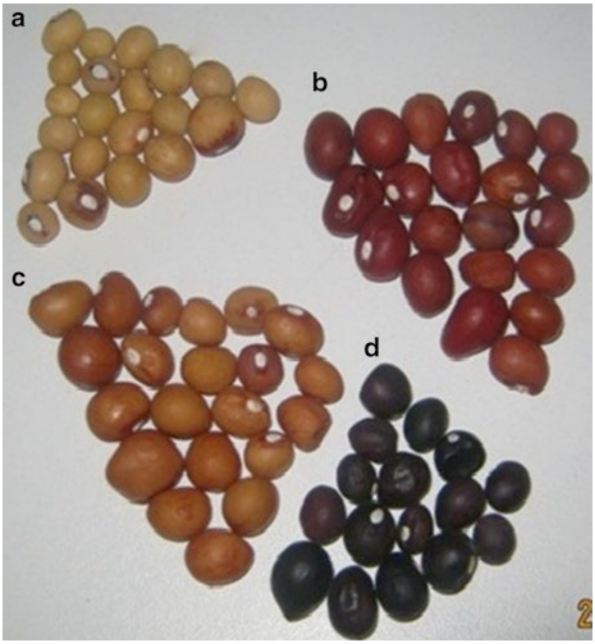

Fig. 3 A sole crop of taro. Farmers in Umbumbulu rural district typically grow their taro as sole crops

thus exposing farmers to food and nutrition insecurity in the event of crop failure. This has resulted in a shift from traditional cropping systems, which have historically been diverse and shown to be effective in safe guarding rural household food security (Azam-Ali 2010). One such crop species in danger of being forgotten is bambara groundnut (*Vigna subterranea* L. Verdc), an underutilized crop whose production has declined drastically over the years.

Although bambara groundnut, a legume with much potential for bolstering food security, has been reported to be drought tolerant (Linnemann and Azam-Ali 1993), its cultivation in pure stands remains relatively uncommon. Similar to taro, it too is preserved by mostly women (Mukurumbira 1985) who intercrop it with crops such as maize, millet, sorghum, cassava, yam, peanut and cowpea (Karikari 2003). Globally, focus has been shifting to research on neglected underutilized species, as possible future food security crops. This could be because the cropping systems in which they are cultivated and the people who manage, protect and consume them represent elements of agro-biodiversity (Azam-Ali 2010). Additionally, the fact that climate change is underway (Hassan 2006) has emphasized the need for identifying resilient crops and farming systems. Intercropping taro and bambara may offer farmers the opportunity to mimic this historical diversity.

According to a recent review by Lebot (2009), in the Asia-Pacific, intercropping of taro in rainfed agroforestry systems is a widespread practice. There are several reports in literature highlighting successful intercropping of taro with several crops.

Silbanus and Raynor (1993) reported that intercropping taro with black pepper (*Piper nigrum*) was beneficial to black pepper in that it resulted in decreased incidence of *Phytophthora* root rot and reduced weed pressure. This was evidence to the concept of sustainability in intercrops. De la Peña and Melchor (1993) intercropped taro with alfalfa, sweet corn, peanut, sweet potato and sugar bush. Their results showed that intercropping had no agronomic effect on corm yield of taro. More recently, Silva et al. (2008) evaluated the influence of intercropping taro with *Crotalaria juncea*, a legume, on leaf development and productivity under organic management. They found that taro grew taller in response to intercropping and that yield was not affected by intercropping. The increased vegetative growth observed in taro may have been due to improved availability of nitrogen in the soil. In these instances, results showed that intercropping had no effect on corm yield of taro. Local farmers in South Africa who also rely on rainfed farming do not currently practice intercropping. Furthermore, there is no information describing intercropping of local taro landraces.

There are few reports in the literature describing intercrops with bambara groundnut. Karikari (2003) reported on intercrops whereby bambara was intercropped with cereal crops (millet, sorghum and maize). In this case, intercropping with bambara was shown to improve yields of both crops; intercropping bambara groundnut with sorghum was more profitable than either maize or millet (Karikari 2003). The positive effect of bambara in these intercrops may have been due to the fact that it is a legume capable of fixing atmospheric nitrogen. This would be beneficial to the cereal crops which are typically heavy feeders of nitrogen.

Intercropping taro and bambara groundnut landraces may be beneficial with regards to increasing crop diversity, strengthening household food security and sustainability of agriculture. Here we use a well-replicated study that was conducted in the Umbumbulu district of KwaZulu-Natal to demonstrate that intercropping of NUS is feasible and beneficial. Over the years, farmers in Umbumbulu have moved towards organic farming of taro such that its cultivation has increased. However, the case is that monocropping of taro in farmers' fields may not be sustainable. There is generally a net exportation of nutrients. In this case, intercropping taro, with a lesser common crop – bambara groundnut – may add to the diversity of the local agro-system.

2 Intercropping

Intercropping has been defined as the growing of two or more different crop species "simultaneously" on the same piece of land or field in both space and time and with overlap at least during part of each crop's growing season (Willey 1979; Ofori and Stern 1987; Baldy and Stigter 1997). Within the context of an intercrop, "simultaneous" implies that the crops grow together for a significant part of their growing periods. Other authors (Willey 1979) have used this to distinguish intercropping from relay cropping, although the latter is generally accepted as a form of intercropping. The spatial arrangements of the component crops can be arranged in several ways, which may include, but are not limited to:

(i) row intercropping – growing two or more crops at the same time with at least one crop planted in rows. This system is more aligned to conventional agriculture and will serve as the scenario for the case study described in this review,
(ii) strip intercropping – growing two or more crops together in strips wide enough to allow for separate, mechanized crop production. This arrangement is often most desirable whereby at least one or both crops are to be machine harvested; however, the component crops should remain in proximity to allow for interaction,
(iii) mixed intercropping – growing two or more crops in no distinct row arrangement which is more typical of traditional agro-systems. As mentioned earlier, some text may not necessarily refer to this as a form of intercropping but rather 'mixed cropping (Ruthernberg 1971; Andrews and Kassam 1975; Freyman and Venkateswarlu 1977; cited in Willey 1979) and
(iv) relay intercropping – planting a second crop into a standing crop at a time when the standing crop is at its reproductive stage but before harvesting.

Willey (1979) stated that intercropping had long been recognized as a common agricultural practice in the tropics. This view was also shared by Walker (2009) who also stated that, in the tropics, many of the traditional cropping systems comprised more than one crop growing in one field at any given time. However, despite this historical contribution, intercropping has mostly been regarded as a primitive practice. This has meant that there has been very limited research on intercropping as opposed to the volumes of research done on sole crops – which have been thought to be the future. The status of intercropping as a farming practice is almost identical to the status of neglected underutilised crop species (NUS). They too form part of historical cropping systems and have been sidelined by research in favor of the major crops – rice, wheat, maize and potato.

Looming climate change predicting increased temperatures and frequency and intensity of droughts in the tropics (de Wit and Stankiewicz 2006; Hassan 2006) poses a significant threat to the hegemony held by sole cropping, as a practice, and the major crops. Both are expected to struggle under these conditions of predicted climate change (Baye et al. 2001), posing a serious threat to global food security, especially in the tropics. There is now a growing need for research on intercropping as well as on NUS. Although such efforts have taken off, albeit slowly, they also appear to be occurring separately. Studies on intercropping have been focused on evaluating mostly cereal-legume intercrop combinations of the major crops. On the other hand, studies on NUS have primarily been conducted as sole crops. Given the potential that these two – intercropping and NUS – could have in contributing towards future food security in the tropics, it is also imperative that intercrops comprising NUS be also studied. In a future whereby resources are set to become more limiting, intercropping NUS could hold the key to maximizing resource utilization.

3 Resource Utilization

Intercropping is known for its main advantage of allowing plants to efficiently utilise available resources of light, water and nutrients thence increasing productivity (Lithourgidis et al. 2011). Component crops use natural resources differently and therefore make better overall use of them than when grown as sole crops (Willey 1979). They are able to completely absorb and convert natural resources such as light, water and nutrients to crop biomass and thus improve yield production. This occurs due to the fact that component crops have different competitive abilities for resources due to variation in crop characteristics such as rates of canopy development, final canopy size, photosynthetic adaptation of irradiance conditions and rooting depth (Midmore 1993; Morris and Garrity 1993; Tsubo et al. 2001).

Light interception is perhaps the most important factor affecting productivity of intercrops. Since radiation intercepted depends on canopy size and duration (Black and Ong 2000), this provides a scenario whereby it can be manipulated by varying plant density and spatial arrangements within the intercrop. Thus, selection of crops that differ in competitive ability in space or time is important (Lithourgidis et al. 2011). Previous research has shown that intercropping is more efficient when component crops differ greatly in growth duration (Wien and Smithson 1981; Smith and Francis 1986; Fukai and Trenbath 1993; Keating and Carberry 1993). Rao and Willey (1980) found that intercropping late maturing pigeon pea with early maturing setaria improved the Land Equivalent Ratio (LER); LER is a measure of the efficiency of intercropping in relation to monocropping. This review evaluated the case of an intercrop whereby the plant density of one component crop – bambara groundnut – was manipulated. Figure 4 shows the different intercropping combinations of a taro-bambara groundnut intercrop. Furthermore, the two component crops – bambara groundnut and taro have very

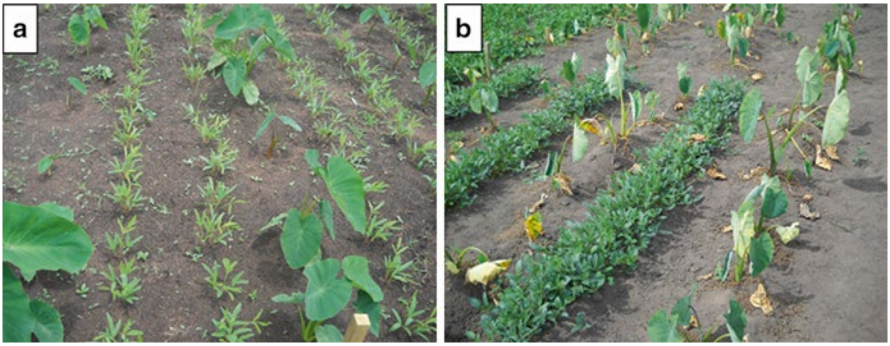

Fig. 4 Different combinations of taro and bambara groundnut planted in an intercrop. (**a**) shows the 1:2 Taro: Bambara groundnut combination whereby two rows of bambara groundnut were planted between two rows of taro and (**b**) shows a 1:1 Taro: Bambara groundnut combination

different growing periods. Typically, bambara groundnut matures in about 150 days after sowing while the taro landrace used takes an average of 6–8 months after planting to mature.

Intercropping has also been reported to improve water-use efficiency (WUE) thereby improving the use of other resources (Hook and Gascho 1988). Intercropping has been reported to result in increases in WUE (18–99 %) relative to WUE of sole crops of component crops (Morris and Garrity 1993). In separate studies, Sani et al. (2011) observed better water-use in a maize-sorghum intercrop and Oseni (2010) observed it in a sorghum-cowpea intercrop. High leaf area and leaf area index have been identified as some of the factors which contribute to water conservation in intercropping (Ogindo and Walker 2005). Morris and Garrity (1993) found that intercropping improved water capture by 7 % compared with monocropping. Water-use efficiency of maize-soybean intercropping was high when compared with the maize and soybean mono crops (Barhom 2001). Therefore intercropping can be a very useful cropping method in water scarce areas. Here, we intercropped taro and bambara groundnut landraces. Typically, taro is less efficient at utilising water compared with bambara groundnut which is widely reported to be drought tolerant. Thus, theoretically, an intercrop combination of these two NUS could result in a scenario whereby there is improved water-use translating to greater biomass achieved by farmers.

Differences in root and canopy architecture of component crops provides a platform for harnessing more light, improved water- and nutrient- use than root and leaves of a sole crop (Thayamini and Brintha 2010). Dahmardeh et al. (2009) reported that maize-cowpea intercropping increased soil nitrogen, phosphorus, and potassium content in relation to maize mono crop. Similar growth pattern of one species creates within-species competition in that growth rate and orientation are similar. Intercropping between high and low canopy crops can improve light interception and consequently yield (Azam-Ali et al. 1990). In the case of this review, taro and bambara groundnut were intercropped. The two exhibit different canopy architecture, and size as well as different rooting depths. On one hand, taro is characterised by large leaves compared with the small leaves of bambara groundnut. In addition, taro plants grow taller than bambara groundnut plants. Lastly, taro has shallow roots while relative to taro, bambara groundnut has a deeper rooting system. Intercropping taro and bambara groundnut would thus create a scenario whereby the root density in the soil is increased. Increased root density implies enhanced soil water capture which would translate to greater biomass production.

While taro, a starchy crop, is reported to be not very drought tolerant and a heavy feeder of nutrients, especially nitrogen due to its large leaves (Lebot 2009), bambara groundnut, on the other hand, is said to be drought tolerant (Linnemann and Azam-Ali 1993) and is also a legume with ability to fix atmospheric nitrogen. Inclusion of legumes in intercrops also boosts the dietary nutrients produced per unit area of land (Mukhala et al. 1999). This also alludes to the concept of sustainability.

4 Sustainability

Nowadays, issues of sustainability always take centre stage in most debates. This is because the world's resources, chiefly water and land, are limited. As such, as we advocate for the promotion of NUS and alternative farming practices, such discussions should also focus on sustainability. Such sustainability should be long-term, enhance the environment as opposed to degradation and still meet the objective of feeding the human population. Here we will define 'sustainability' according to (Sivakumar et al. 2000) who described sustainability as the balance between utilization to satisfy human needs and maintenance of the environment. Hansen (1996) also provides some useful definitions of sustainability that are specific to agriculture. Since sustainable agriculture seeks, in most cases, to mimic nature, intercropping offers a rare window to achieve such. Intercropping increases on-farm diversity, maximizes on resource use and conversion to biomass as well as improving water- and nutrient-use. Other benefits of intercropping may also include reduced incidence of pests and disease in intercrops as well as reduced requirement for labor for weeding. This amounts to savings (financial and human resource) for resource-constrained farmers. Theoretically, this creates a balance between providing food and fiber for man, enhancing the environment and avoiding environmental degradation. This implies that intercropping is indeed a sustainable farming practice.

5 Materials and Methods

5.1 *Planting Material*

An eddoe type taro landrace was obtained from subsistence farmers in the Umbumbulu rural district (29°36′S; 30°25′E) in KwaZulu-Natal, South Africa. Seeds of a bambara groundnut landrace were collected from subsistence farmers in Jozini (27°26′S; 32°4′E), northern KwaZulu-Natal, South Africa. The bambara landrace was characterized according to seed coat color (Sinefu 2011) and thereafter the "Red" landrace was used in this study.

5.2 *Site Description and Experimental Design*

Field trials were planted at a homestead in Umbumbulu (29°36′S; 30°25′E), located in the midlands of KwaZulu-Natal, over two summer seasons (2010/2011 and 2011/2012) under dryland conditions. The soils at the trial site were classified as sandy clay loam (USDA Classification). The field chosen for the trials had been previously fallow for two seasons.

The experiments were arranged in a randomized complete block design, replicated three times. The component crops were taro and bambara groundnut. Treatments included taro and bambara sole crops each, and two intercrop combinations. The intercrop combinations were 1:1 (taro: bambara groundnut) and 1:2. Plant spacing for taro was 1 m between rows × 0.5 m within rows. Within-row spacing for bambara groundnut was 0.3 m.

Soil sampling was done prior to plant for determination of soil fertility and textural properties. For both seasons, the field to which the trials were planted was prepared by local farmers using hand-hoes. In line with the organic farming practices of the community, an organic fertilizer (Gromor Accelerator) was applied prior to planting. Weeding and general maintenance of the trials were done by the farmers.

5.3 Data Collection and Analyses

Data collection, for both seasons, was done weekly to determine plant growth parameters of height and leaf number. At harvest, biomass (B), yield (Y), yield components and harvest index (HI) for each crop were determined. Productivity of the intercrop was evaluated using the Land Equivalent Ratio (LER) as described by Willey (1979):

$$LER = L_A + L_B = \frac{Y_A}{S_A} + \frac{Y_B}{S_B} \qquad (1)$$

Where L_A and L_B are the partial LERs of taro and bambara, respectively, Y_A and Y_B are the intercrop yields of taro and bambara, respectively, and S_A and S_B are their respective sole crop yields.

Data were analyzed using the analysis of variance (ANOVA) algorithm in GenStat® (Version 14, VSN International Ltd, UK). Duncan's Multiple Range Test (DMRT) was used for mean separation at the 5 % level of significance.

6 Results and Discussion

6.1 Crop Growth

For both seasons, taro growth (plant height and leaf number) was negatively affected ($P < 0.05$) by intercropping (Fig. 5). Increasing the proportion of bambara in the intercrop resulted in a decrease in both plant and leaf number of taro in the 1:1 and 1:2 intercrops, respectively, compared with the sole crop. However, despite this decrease, plant height in the sole crop was statistically similar to the 1:1 intercrop.

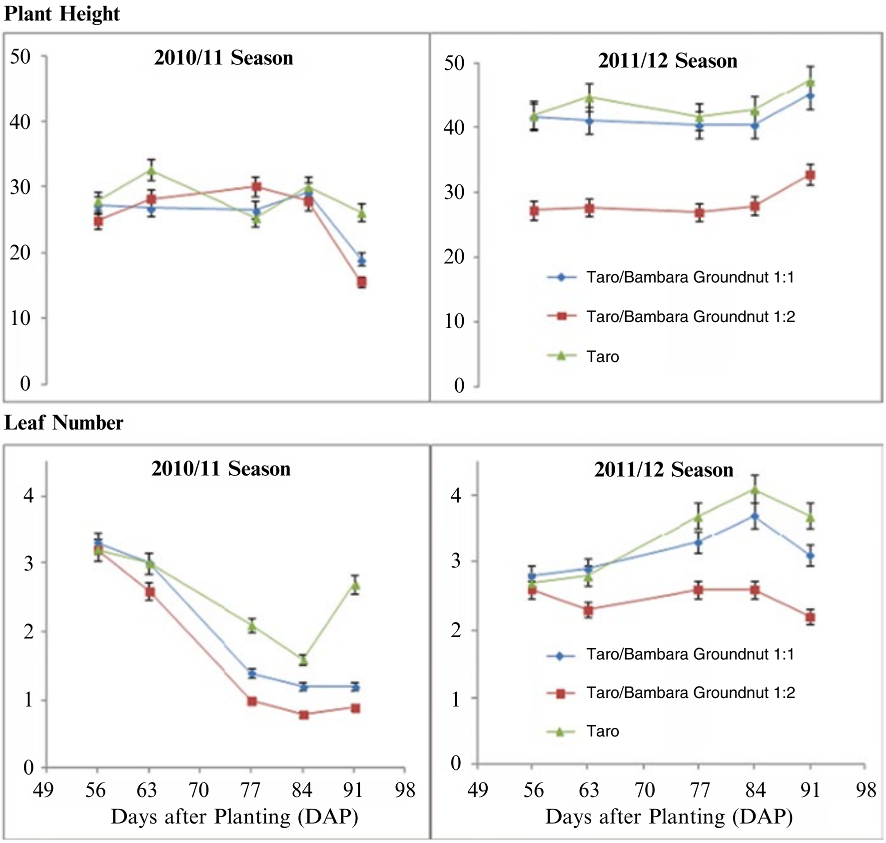

Fig. 5 Comparisons of plant height and leaf number of taro grown under sole cropping, 1:1 and 1:2 intercropping grown during 2010/2011 and 2011/2012 planting season

Results of leaf number, for both seasons, showed a similar trend as that observed for plant height; sole cropping produced the most leaf number compared with the 1:1 and 1:2 intercrops, respectively (Fig. 5).

Contrary to our findings, Silva et al. (2008) observed taller plants and no changes to leaf area when intercropping taro with a legume *Crotalaria juncea*. The results of the present study may have been due to increased inter-species competition for resources such as water and nutrients. However, bambara is reported to have a deep root system (Swanevelder 1998) compared with the shallow fibrous roots found in taro (Lebot 2009). This would imply that the two crops can co-exist since they can access water from different levels of the soil profile. In this study, it was shown that intercropping taro and bambara at a ratio of 1:1 resulted in growth that was statistically similar to that observed under sole cropping.

It was observed that intercropping had variable effects on growth of bambara. During the 2010/2011 season, increasing the proportion of bambara increased plant

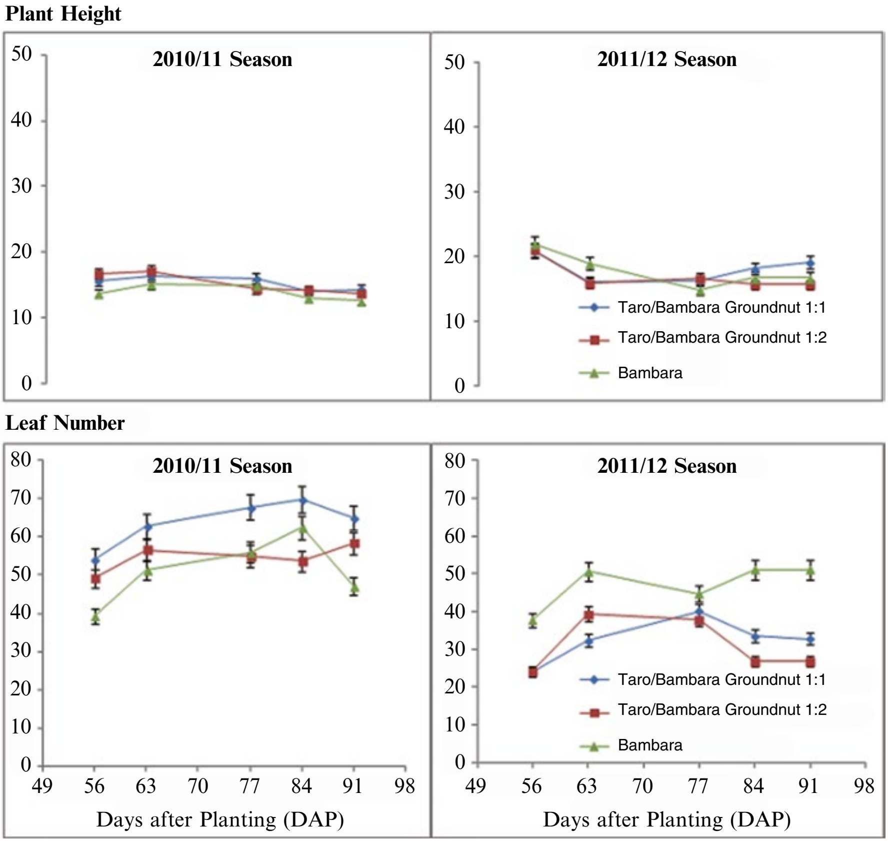

Fig. 6 Comparisons of plant height and leaf number of bambara grown under sole cropping, 1:1 and 1:2 intercropping grown during 2010/2011 and 2011/2012 planting season

height and leaf number (Fig. 6). Intercropping had a positive effect ($P<0.001$) on plant height and leaf number of bambara; plants in the 1:1 and 1:2 intercrops were taller and had more leaves compared with the sole crop (Fig. 6).

In line with the trend for plant height established in the first season, no significant difference ($P>0.05$) was found in plant height between the sole crop and two intercrops during the 2011/2012 season (Fig. 6). Intercropping bambara at a ratio of 1:1 resulted in taller plants compared with sole cropping and intercropping at a ratio of 1:2 (Fig. 6). Contrary to the previous season's findings, intercropping resulted in significantly ($P<0.001$) fewer leaves compared with sole cropping. This may have been due to increased intra- and inter-specific competition for resources such as light and water as well as possibly the effect of shading from adjacent taro plants. However, this study showed that intercropping taro with bambara at a ratio of 1:1 had a positive effect on growth of bambara.

Table 1 Yield and productivity of a taro – bambara intercrop under dryland conditions

Season	Intercrop	Taro yield (t ha^{-1})	Bambara groundnut yield (t ha^{-1})	LER^{x}
2010/2011	**Sole crop**	6.29ab	0.34ab	–
	1:1	5.03ab	0.31ab	1.71a
	1:2	4.55ab	0.22b	1.36b
	Mean	**5.29^{a}**	**0.29^{b}**	**1.54^{a}**
2011/12	**Sole crop**	6.98a	0.97a	–
	1:1	5.66ab	0.51ab	1.34b
	1:2	3.88b	0.53ab	1.10b
	Mean	**5.51^{a}**	**0.67^{a}**	**1.23^{b}**
LSD$_{(P=0.05)}$ (Intercrop)		**1.82**	**0.44**	**0.217**
LSD$_{(P=0.05)}$ (Season)		**1.48**	**0.36**	**0.217**
LSD$_{(P=0.05)}$ (Int*Season)		**2.57**	**0.62**	**0.307**

Numbers with different letters in the same column differ statistically at the 5 % level of significance

Letters in bold superscript represent differences between seasonal means across intercrop treatments at LSD (P = 0.05) (Season)

^{x}*LER* land equivalent ratio

6.2 Yield and Intercrop Productivity

For both seasons, intercropping had no significant effect ($P>0.05$) on corm yield (t ha^{-1}) of taro (Table 1). Despite lack of statistical differences this study showed that sole cropping consistently yielded higher than intercropping at ratios of 1:1 and 1:2, respectively. This is in line with the sole crop having a larger canopy relative to the intercrops, thereby implying a greater source size capable of partitioning more assimilate to the corms (sink). Reduced canopy size in the 1:1 and 1:2 intercrops may have resulted in a smaller source, while the increased corm number per plant meant a bigger sink thus resulting in less assimilate being partitioned to the numerous corms. There are various benefits of intercropping taro with legumes (de la Peña and Melchor 1993). Although taro yields were lower than those reported by de la Peña and Melchor (1993), our results were similar with their observations that there were no significant differences between treatments. Silva et al. (2008) also reported that intercropping had no effect on taro yield. Here we showed that intercropping taro with bambara at a ratio of 1:1 had negligible effect on corm yield of taro suggesting that farmers would not face a loss in possible income if they were to intercrop.

According to Willey (1979), one criterion for intercropping is to evaluate if intercropping a main crop with another crop will not affect yield of the main crop. Under this objective, it may be assumed that any yield obtained from the second crop will be acceptable to the farmer (Willey 1979). In the present case, we sought to evaluate whether intercropping taro with bambara would not affect yield of taro, which the farmers rely on as a cash crop, hence any yield of bambara achieved would be deemed acceptable. It is important to note that, for all cases, our yields of bambara achieved in the intercrops (Table 1) were comparable to results of bambara recorded in experiments where bambara was grown in pure stands (Sinefu 2011). So we were able to show that intercropping taro with bambara at a ratio of 1:1 would not affect their taro yield, but also offer them decent yields of bambara for their dietary requirements.

Productivity of the intercrop was evaluated using the Land Equivalent Ratio (LER). The LER was developed to evaluate yield advantages to intercropping (Walker 2009) and is preferable and has merit in that it can be applied to any intercropping situation (Willey 1979). In this study it was consistently shown that, over both seasons, intercropping taro with bambara was more productive than growing either of the two crops in pure stands. The findings of this study concur with de la Peña and Melchor (1993) that intercropping taro with beans and other legumes was productive. Moreover, we showed that intercropping taro with bambara at a ratio of 1:1 was most productive and had no effect on corm yield of taro as the main crop, while also producing acceptable yields of bambara groundnut. Previous reports (Karikari 2003) have been to the contrary suggesting that bambara intercropping systems were less productive than sole crops of their component crops (Table 1).

Results of this study suggest that taro and bambara are complimentary crops. Such complimentarity may derive from benefits of leaf shading by taro – reducing air temperatures to near optimum, reduction of soil evaporation, weeds, pest and disease incidence (Midmore 1993). Some of the benefits were visible during the trials, in terms of frequency of weeding – intercrop plots required less weeding compared with sole crop plots. In addition, bambara matured fast (on average 140 days after planting – data not shown) compared with an average of 210 days after planting in taro (data not shown) ensuring ease of harvest. Together, this could represent savings in labor for the household, allowing for more time to be allocated to other tasks as well as ensuring increases in dietary nutrients produced by the farmers in a sustainable way.

7 Conclusion

This study shows that intercropping taro with bambara at a ratio of 1:1 has no deleterious effect on growth of both taro and bambara. Growth of taro was mostly affected by rainfall distribution during the season; future research will focus on selection of planting dates as a management tool for managing rainfall distribution associated water stress. Inclusion of bambara (a nitrogen-fixing plant) in taro cropping systems is complimentary in that taro and bambara roots extract water from different depths of the soil profile while intermingling of roots improves utilization of soil nutrients. Intercropping taro with bambara is highly productive, in terms of additional output per unit area of land accrued from the bambara crop, with no significant negative effect on yield of the main crop – taro. The 1:1 intercrop had an LER of 1.53 compared to 1.23 for the 1:2 intercrop, indicating there was an advantage to intercropping. Lastly, intercropping taro with bambara is productive, sustainable and beneficial such that it improves farmers' nutritional productivity per unit area of land under cultivation compared with sole cropping taro.

Acknowledgements Water Research Commission of South Africa K5/1771/4 Water-Use of Drought Tolerant Crops. WRC Knowledge Review 2008–09.

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Land Productivity and Food Security in Zhangjiagang, China

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Ting Tian, Lijian Wang, and Jianlong Li**

Abstract Urbanization, industrialization, population expansion and other economic activities have been occurring among different regions in China in varying degrees. Zhangjiagang city is one of the fastest growing cities among all Eastern Chinese cities and was chosen in the current investigation as a city of China in miniature for studying the cultivated land instability degree (CLID) based on 3S technologies and cellular automaton models, the productivity changes of main grain crops and agricultural ecological security situations by using remote sense and geographic information system (GIS) technology during the period of 2004–2008. The results indicated that the CLID value in Zhangjiagang city had obvious spatial heterogeneity. Faster reduction of cultivated land occurred in the area with higher CLID value.

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Although the area of cultivated land in Zhangjiagang city reduced year by year, the food amount per capita did not show significant changes due to gradually increasing crop yields. During this period, the agricultural ecological deficit in Zhangjiagang city increased by 16.23 %. The Grassland ecological deficit had the largest proportion, and cultivated land ecological deficit increased slightly, but the forest ecological deficit and the hydrosphere ecological deficit remained stable. Steady decline in agricultural land area and drop in agricultural ecological carrying capacity were probably the main reasons to cause the consequences. The results of this investigation in Zhangjiagang may project the tendency of urbanization, industrialization, population expansion and other economic activities nationwide in China.

Keywords Cellular automaton models • Cultivated land instability degree (CLID) • Food security • Productivity of cultivated land • 3S technologies

1 Introduction

With the fast development of urbanization in China, great changes in most of the medium and small-sized cities have taken place in industry structures, with agriculture as the leading factor. Industrialization, population expansion and other economic activities have also impacted the agricultural production, and thus resulted in serious cultivated land instability which led to cultivated land loss and food security problems (Kang et al. 2002; Wang and Liao 2006). Agriculture is the foundation of national economy, and thus the foundation of grain and economy security. As one of the most important factors of agriculture and the most essential part of land use, the quality and quantity of cultivated land determines the grain production, which decides the survival and evolvement of human kind (Liu et al. 2007). However, China is very poor in its land resources. The improvement of economical level and fast development of urbanization have made land use competition more and more severe among various departments. Cultivated land instability degree (CLID) can be mainly reflected in the disturbance on the crop land by human activity (Gan et al. 2009). The high instability degree of the arable land often results in two consequences: (1) the farmers plant industrial crop instead of food crop for greater profits; (2) agricultural land is transformed to non-agriculture land use because of the quality declining of crop lands. The higher the instability degree is, the higher probability the cultivated land use will be changed. This inevitably leads to increasing agricultural intensification with lots of problems (Alauddin and Quiggin 2008; Lemaire et al. 2005; McIntyre and Lavorel 2007).

As remote sensing technology provides information on land-cover dynamics with better precision, accuracy and frequency, GIS has broadened the scope of regional researching and planning, imagery-based model simulation land-use/land-cover change has become more accurate and more accepted (Goodchild 2000; Keys and McConnell 2005; Silva and Clarke 2002). At the same time, the cellular automaton models are also used to analyze the land use change. Over the past decade, modeling urban expansion based on cellular automaton techniques has been flourishing (Fang et al. 2005; He et al. 2008; Jenerette and Wu 2001; Li and Yeh 2000, 2001; Liu et al. 2008; Yeh and Li 2006). These studies have demonstrated cellular automaton can simulate complex urban dynamics as a powerful tool (Yang et al. 2009).

As one of the fastest developing areas, Yangtze River delta is also the most important city cluster in China. Zhangjiagang city, typical representative of many medium and small-sized cities in the delta, has witnessed the quick pace of its urbanization and fast development of its economy since the reform and opening-up policy. In the first 10 years of the twenty-first century, as a result of fast development of urbanization and industrialization, expansion of population and activity of its economy, Zhangjiagang city has transformed from the agriculture-dominated economy into the industry structure that is dominated by both second and tertiary industry. Consequently, Per Capita GDP of Zhangjiagang and the living quality of the people in this area has greatly improved, while the cultivated land becomes scarcer. The scarcity of farm land, on the one hand, reduces the grain production of the area; and on the other hand, increases the insensitivity and degenerativity of the land use (Kang et al. 2002; Wang and Liao 2006). On the basis of a multitude of remote sensing pictures (including ETM, SPOT, IRS-P6), graphs of land use, population distribution, and annual grain production in the past several years, the current research quantitatively studies the instability of cultivated land under the present situation by correcting and interpreting these remote sensing pictures, calculating the areas of lands used for different purposes, and improving cellular automaton model. The research results would be of great importance to reasonable use of farm land and sustainable development of the city.

2 Materials and Methods

2.1 Study Area

Zhangjiagang city is located in Jiangsu province on the eastern China between 31°43′12″ ~ 32°02′ N and 120°21′57″ ~ 120°52′ E, and has a subtropical monsoon climate, with annual mean temperature of 15.2 °C. Annual mean precipitation of Zhangjiagang is approximately 1,000 mm, with 60 % of rainfall occurring during April–September (Yang et al. 2009). Zhangjiagang city covers approximately 998.48 km^2 which contains nine towns and is now one of the fastest growing cities among all eastern Chinese cities, with the population increasing from 828.9 thousand in 1996 to 897.3 thousand in 2008 (Fig. 1).

The area of cultivated land in Zhangjiagang region was 35.3 thousand hm^2 in 2008. Since 1990, Zhangjiagang region had experienced a dramatic change which had altered predominant agricultural industrials for more manufacturing and services management. A great number of agricultural lands had been transformed to

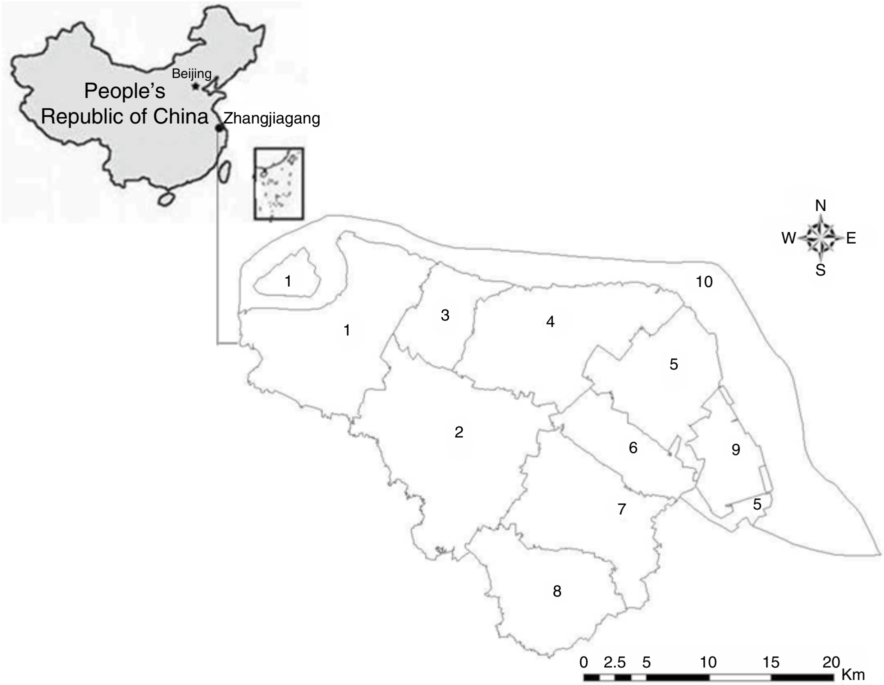

Fig. 1 Study area and the location of towns in Zhangjiagang (*1* Jingang town, *2* Yangshe town, *3* Daxing town, *4* Jinfeng town, *5* Leyu town, *6* Nanfeng town, *7* Fenghuang town, *8* Tangqiao town, *9* Changyinsha, *10* The Yangtze river)

urban area and its urban fringe had constantly advanced outward into the surrounding agricultural land. Along with industry and land use change, the changes of agricultural production and management had also taken place. The areas of cultivated land had decreased from 45.0 thousand to 35.3 thousand hm^2 during the period of 1996–2008, while planting areas of the industrial crop (mainly cotton and rape seeds) had increased from 12.1 thousand to 16.8 thousand hm^2.

2.2 Material Acquisition and Pretreatment

The 1: 10,000 land use maps of 2004 and 2008 were kindly provided by the local government. The land use maps of 2004 and 2008 were classified into six patch types (or classes): residential land, crop, grass, forest, roads, and water. The residential class included various dwellings, commercial, industrial, and public institutions (e.g., educational and correctional facilities). In addition, Landsat-7 ETM+image acquired on September 23rd, 2004 was collected for the case study. The geometric rectification, unsupervised classification and supervised classification of the image were carried out by the ERDAS IMAGINE software. All the data layers were registered to the same UTM coordinate system and sampled to the grid based map with a same pixel resolution of 250 m. Then It was geometric rectified by the 1:10,000 land use map of 2004 made by local government at least 30 evenly Ground Control Points (GCP). The Root Mean Squared Errors of geometric rectification were all less than 0.8 pixels (Yang et al. 2009).

Differences between the land use maps of 2004 and 2008 were compared, which indicated the land cover changes during 2004 and 2008 in Zhangjiagang region. GIS layers were calculated to illustrate the distribution where crop land was transformed to urban land use and the locations of new industrial crop land in 2008. These two layers were used as the primary reference data for the evaluation of simulation results in the research. The majority of the locations, where new industrial crops were planted or agriculture land use was transformed, should be located within the high CLID areas. Other related data were all from Zhangjiagang statistical yearbook.

2.3 Research Methods

Model methods are widely used in many process studies of ecology (Lambin et al. 2000), which, to a great extent, represent one part of the complexity of land use and are thus developed to manage the farm land and predict the change of it in the future (Sorel et al. 2010; Veldkamp and Lambin 2001). With the increasing accuracy of remote sensing data and the strong power of GIS, the model methods, basing on remote sensing pictures, have been widely used (Goodchild 2000; Keys and McConnell 2005; Silva and Clarke 2002). Since CLID could be affected by many factors, such as the distance between the farm land and urban center or main road, population distribution, economic level, land type, gradient, cellular automaton was adopted in this study to analyze CLID distribution in this area. Because the main influencing factors investigated in cellular automaton models before were about geography and natural aspects, and the cultivated land instability was still influenced by the social economic factors, therefore, it was quite necessary to integrate the influencing factors of natural attributes and social economic attributes (Lambin et al. 2000). A better way is to integrate the likely model method into cellular automaton model, and combining remote sensing data to study the land use change (He et al. 2008; Weber and Puissant 2003).

In recent years, some scholars begin to pay close attention to the research of land capacity at the county level, and the way of ecological footprint analysis was one of them. Ecological footprint analysis was to transform the regional resources and energy consumption into various necessary biological production land area (Ecological footprint), then compared the ecological footprint with regional land area, which can provide necessary biological production (Ecological carrying capacity), the results could quantitatively judge that a regional development was in ecological deficit state. And ecological carrying capacity was a support ability that ecological system provided resources and environment to human social system

(Tang et al. 1997), for the ecological system of agriculture, ecological carrying capacity emphasized that the economic growth degree could not exceed in the sustaining scope of the system, its essence was to put forward a long-term restriction for economic development, if the economic development exceeded the restriction, the agricultural ecosystem of this region was in ecological deficit state.

2.4 Cellular Automaton Models and Parameters

To quantify the regional CLID, a possibility model was borrowed from urban expansion study (Barredo et al. 2003). If ${}^{t}P_{x,y}$ was defined as regional CLID at time t, it can be expressed as:

$$ {}^{t}P_{x,y} = f({}^{t}D_{x,y}, {}^{t}R_{x,y}) \tag{1} $$

Where ${}^{t}D_{x,y}$ is the driving force for enhancing CLID value of cell(x,y), and ${}^{t}R_{x,y}$ is the limiting factor to improve CLID value. The driving factors in formula (1) include natural-ecological factor, geography- space factor and social-economic factor. In addition, according to the first law of cognitive geography, the effects of Adjacent ground objects on center cell are very important (Tobler 1970). So, ${}^{t}D_{x,y}$ is obtained by:

$$ {}^{t}D_{x,y} = f({}^{t}S_{x,y}, {}^{t}N_{x,y}, {}^{t}TU_{x,y}) \tag{2} $$

Among them, ${}^{t}S_{x,y}$ is a suitability factor for enhancing CLID value of cultivated land cell (x, y), and ${}^{t}N_{x,y}$ is the effect of neighbors on cell (x, y), while ${}^{t}TU_{x,y}$ is a possibility under the influence of population and economic factors for enhancing CLID value of cell (x, y). According to the form of possibility model, ${}^{t}TU_{x,y}$ can be expressed as:

$$ {}^{t}TU_{x,y} = \sum_{i=1}^{n} \log_{10}\left(1 + \frac{P_i}{D^{b}_{(x,y,x_i,y_i)}}\right) + \sum_{i=1}^{n} \log_{10}\left(1 + \frac{G_i}{D^{b}_{(x,y,x_i,y_i)}}\right) \tag{3} $$

Where n is the quantity of urban patch in study area. $D^{b}_{(x,y,xi,yi)}$ is the distance between cell (x, y) of agricultural land and urban patch (x_i, y_i), and the distance is euclid distance. G_j is the GDP produced by the urban patch (x_i, y_i), and P_i is the population of the urban patch (x_i, y_i).

The limiting factors in formula (1) include environmental and ecological constraints, such as soil types, slope, etc, which can prevent farmlands into other lands. The government's planning can also become a strong limiting factor, therefore, ${}^{t}R_{x,y}$ can be represented as:

$$ {}^{t}R_{x,y} = f({}^{t}EC_{x,y}, {}^{t}PC_{x,y}) \tag{4} $$

Where ${}^{t}EC_{x,y}$ is the block effect of environmental and ecological factors on enhancing CLID value of cell(x,y), and ${}^{t}PC_{x,y}$ is the limiting function of land use policies to CLID. Through the above descriptions, CA model can be defined as:

$$ {}^{t}P_{x,y} = \left(\sum_{i=1}^{m-2} {}^{t}W \times {}^{t}S_{i,x,y} + W_{m-1} \times {}^{t}N_{x,y} + W_{m} \times {}^{t}TU_{x,y} \right) \times \prod_{r=1} {}^{t}EC_{r,x,y} \times \prod_{l=1} {}^{t}PC_{l,x,y} \quad (5) $$

In formula (5), ${}^{t}S_{i,x,y}$, ${}^{t}N_{x,y}$ and ${}^{t}TU_{x,y}$ are respectively standardization between 1 and 100, so they are convenient for superposition analysis of all factors. W_1, W_2…… W_{m-1} and W_m are weights of each driver factor, they can reflect the contribution degree of each influencing factor for CLID. $\prod_{r=1} {}^{t}EC_{r,x,y}$ and $\prod_{l=1} {}^{t}PC_{l,x,y}$ are decided by the parameter of two values. When the cultivated land is limited by the government planning or natural ecological condition to change as non-agricultural land or change for planting other economic crops, the parameter value is 0, conversely, the parameter value is 1.

Neighbor's influence is a core factor in cellular automaton model. Cellular automaton model defines three neighbors, they are Von Neumann type, Moor type and expansion Moor type. In order to find more appropriate neighbor type for analysis, a series of neighbor radius in expansion Moor type are selected in this study, at last the neighbor whose cell radius is 7 is selected for the study. In formula (5), the influence of neighbor on center cell can be calculated as follows:

$$ {}^{t}N_{x,y} = K \sum_{m=1,n=1}^{c} \frac{1}{d_{x \pm m, y \pm n}} \times I^{t} x \pm m, j \pm n \quad (6) $$

Where C is an integer parameter, and it indicates the neighbor radius, $d_{x\pm m,y\pm n}$ is the distance from cell(x ± m,y ± n) to center cell(x,y). $I^{t}{}_{x\pm m,y\pm n}$ is a parameter of two values, if the initial status of cell(x ± m,y ± n) is 1 at time t, the value of $I^{t}{}_{x\pm m,y\pm n}$ is 1, otherwise it is 0. K is a parameter to normalize the calculated results between 0 and 100.

3 Results and Discussion

3.1 Distribution of Cultivated Land Instability Degree and Change of Cultivated Land in Zhangjiagang City

The CLID (cultivated land instability degree) values in different areas of Zhangjiagang city could be calculated according to the formula (5). Regional CLID values were between 0 and 100. With CLID values increasing, then the instable degree of cultivated land increased, and the possibility was higher for the cell of

Table 1 Cultivated land instability degree (CLID) values and cultivated land decreasing rate in nine districts in Zhangjiagang region (the average CLID value of cultivated land was the highest in Yangshe town and the lowest in Changyinsha town)

Districts of Zhangjiagang	Average CLID values	Proportion areas with a CLID value higher than 40(%)	Decreasing areas of cultivated lands (hm^2/year)
Jingang town	33.95	14.7	3.25
Daxing town	32.61	7.05	1.45
Jinfeng town	33.44	7.72	2.61
Fenghuang town	27.76	3.90	1.68
Leyu town	25.56	1.13	1.80
Changyinsha town	14.18	0.00	0.34
Yangshe town	37.90	30.70	5.60
Tangqiao town	31.64	11.40	1.81
Nanfeng town	34.50	17.70	3.01

cultivated land to change as non-agricultural land or change for planting other economic crops. In order to analyze the change of cultivated land productivity in different areas of Zhangjiagang city, the average CLID values of nine districts/towns in Zhangjiagang city were compared, and the percentage of cultivated land where the CLID values were higher than 40 was also calculated according to the results of cellular automaton models. The average CLID value of cultivated land in Yangshe town was the highest (Table 1). It meant that the town was facing the greatest pressure in changing from cultivated land to non-agricultural land or economic crop land. In addition, the CLID values were higher also in Nanfeng town and Jingang town. The CLID value was the lowest in Changyinsha region (Table 1), and it meant that the cultivated land was relatively stable in this area.

Areas with CLID values higher than 40 were the most biggest in Yangshe town, it showed that large scale decreasing of cultivated land and changing of grain crop land would happen likely under the influence of urban development, population growth, economic levels rising and other factors to meet the needs of urbanization in this region.

3.2 Extraction of Crop Farming Area in Zhangjiagang City

First, the stacking of remote sensing images was achieved with the land use chart, and non-agricultural land was removed, then the classification was carried out. Because of the diverse species of crops in agricultural land, the unsupervised classification was adopted in agricultural land accordingly, and the classification number was preset as 30. On the basis of unsupervised classification, according to the field investigation and visual interpreting, after removing the pixels of garden land, nurseries and so on, and the pixels those may be wheat or rice were chosen. Using area where NDVI ratio of two periods was less than 3, the study area was masked, then precise wheat land was obtained. And water field area can be obtained by using the extraction of water in rice paddies field after transplanting, and then masked to extract rice pixels. Finally, wheat and rice area in different towns can be obtained by using stacking of classification results of different town borders.

Through the further analysis of classification accuracy according to the selected test samples of ground investigation, the results showed that, wheat farming area was 15,266.7 ha, rice farming area was 20,533.3 ha, and total area of wheat and rice was 35,800 ha in Zhangjiagang in 2005. In 2006, wheat farming area was 15,233.3 ha, rice farming area was 19,833.3 ha, and total area of wheat and rice was 35,066.6 ha. In 2007, wheat farming area was 14,600 ha, rice farming area was 20,300 ha, and total area of wheat and rice was 34,900 ha. In 2008, wheat farming area was 14,333.3 ha, rice farming area was 20,433.3 ha, and total area of wheat and rice was 34,766.6 ha. The total planting area of wheat and rice in entire Zhangjiagang region had been reduced gradually year by year.

3.3 Prediction of Main Crop Productivity and Food Quantity Per Capital Possession in Zhangjiagang City

Based on the real situations of gross grain production obtained from the remote sensing statistics in the past 5 years in Zhangjiagang city, a model was built and could be used to predict the future grain production (Fig. 2). Since the number of people in Zhangjiagang city was growing year by year, it was of great necessity to calculate grain production per capita possession and predict whether grain production was safe under the current situation of urbanization. The population growth model used in the study was based on the number of people in Zhangjiagang city from 2002 to 2008 (Fig. 3).

Based on the gross production of main grains and population growth model, the estimation dynamics of rice and wheat of per capita possession could be predicted in Zhangjiagang in the next 10 years. And the grain production of per capita possession did not decrease even though the cultivated land was decreasing year by year (Table 2).

3.4 Ecology Safety of Agriculture in Zhangjiagang City

The analysis of agricultural ecological footprint between 2004 and 2008 showed that agricultural ecological footprint in Zhangjiagang had increased by 8.16 % in these 5 years, rising from 1.2399 ha in 2004 to 1.3411 ha in 2008, while the agricultural ecological biocapacity had dropped by 13.91 %, from 0.3335 ha in 2004 to 0.2871 ha in 2008 (Fig. 4). As a result, agricultural ecological deficit had also increased by 16.23 % during the 5 years. In conclusion, the agricultural development in Zhangjiagang in recent 5 years had been unsustainable.

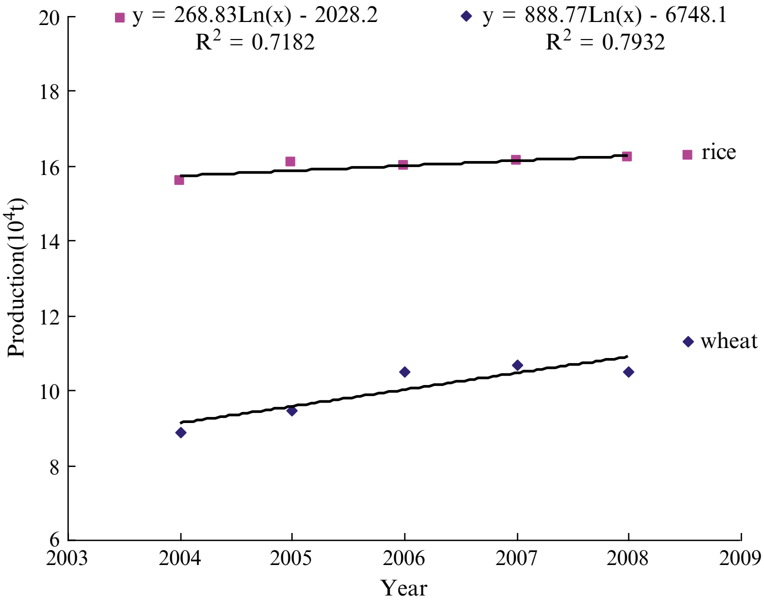

Fig. 2 Production dynamics of rice and wheat in Zhangjiagang region. Based on the dynamics a model was built and could be used to predict the future grain production

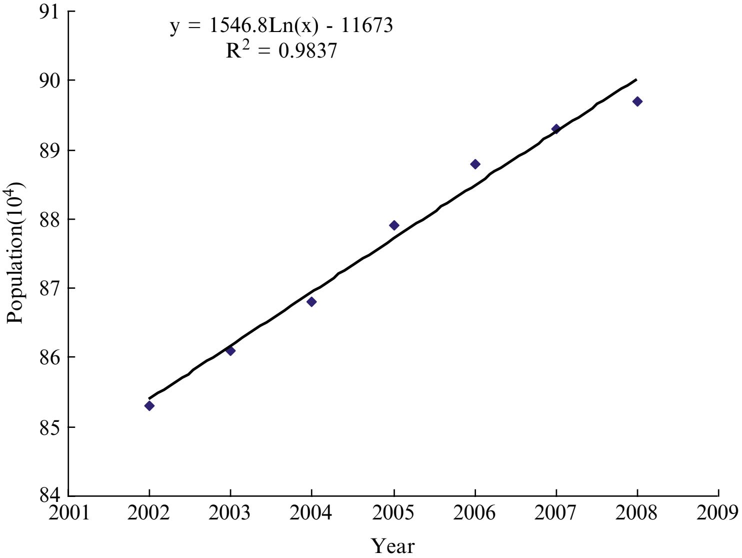

Fig. 3 Population growth in Zhangjiagang region. The model was built to predict the future population based on the number of people in Zhangjiagang city from 2002 to 2008

Table 2 Estimation dynamics of rice and wheat of per capita possession in Zhangjiagang (the grain production of per capita possession does not decrease even though the cultivated land was decreasing year by year)

Year	Estimation yields of rice (10^4 t)	Estimation yields of wheat (10^4 t)	Estimation population (10^4)	Total yields (10^4 t)	Per capita possession (kg)
2011	16.63	12.23	92.56	28.86	311.79
2012	16.76	12.67	93.33	29.43	315.33
2013	16.89	13.12	94.09	30.01	318.95
2014	17.03	13.55	94.87	30.58	322.34
2015	17.16	13.99	95.63	31.15	325.73
2016	17.29	14.44	96.41	31.73	329.11
2017	17.43	14.88	97.17	32.31	332.51
2018	17.56	15.32	97.93	32.88	335.75
2019	17.69	15.76	98.71	33.45	338.87
2020	17.83	16.19	99.47	34.02	342.01

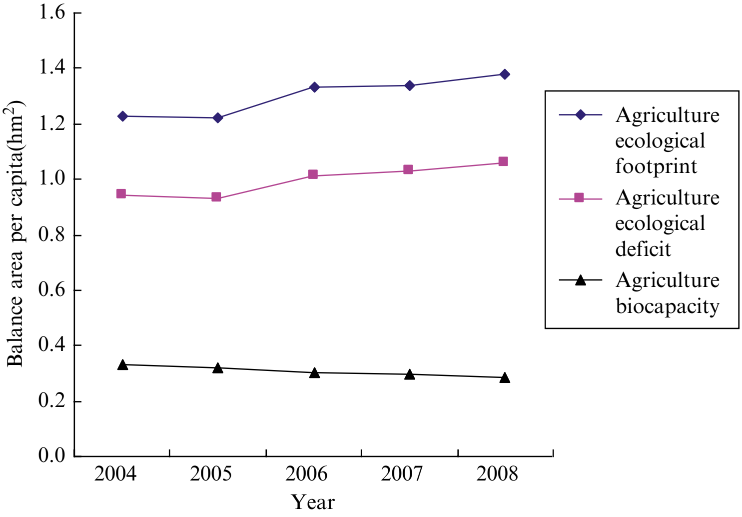

Fig. 4 The change of agriculture ecological footprint, agriculture ecological deficit and agriculture biocapacity in Zhangjiagang. Agricultural ecological footprint in Zhangjiagang had increased by 8.16 % between 2004 and 2008, rising from 1.2399 ha in 2004 to 1.3411 ha in 2008, while the agricultural ecological biocapacity had dropped by 13.91 %, from 0.3335 ha in 2004 to 0.2871 ha in 2008. As a result, agricultural ecological deficit had also increased by 16.23 % during the 5 years

From the analysis of four types of cultivated land (Fig. 5), ecological deficit of grassland accounted for the highest percentage of agricultural ecological deficit and had risen by 22.24 % between 2004 and 2008, from 0.5612 ha in 2004 to 0.6513 ha in 2008. It had become the leading factor contributing to agricultural ecological deficit in Zhangjiagang. Ecological deficit of cropland had been increasing slightly

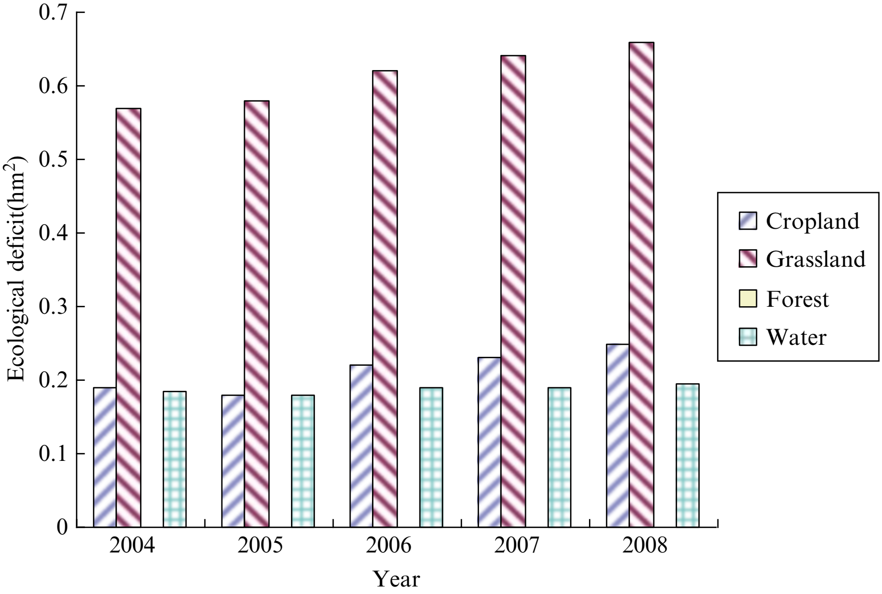

Fig. 5 The change of ecological deficit of cropland, grassland, forest and water in Zhangjiagang (The ecological deficit of forest is zero)

by 0.0402 ha, while ecological deficit of water remained stable and ecological deficit of forest was almost zero during the 5 years.

The above ecological deficit showed that the demands for land, forest, herd, and fishery in Zhangjiagang city was much more than before and was putting much pressure on agriculture. Since the contradiction between overpopulation and cultivated land was becoming more and more severe and the local agricultural supply failed to satisfy the demands of the local economy, Zhangjiagang had to import large amount of grains from other areas or over-exploit the natural ecologic resources.

3.5 *Analysis of Model Sensitivity*

The effect of analysis of cultivated land conversion pressure combining cellular automaton models and economic and population factors was better. In addition, the analysis results of regional CLID were validated by the Fuzzy kappa. Of course, some cultivated lands where CLID value was high in 2008 didn't happen the transformation of arable land type or planting crops, because the regional CLID value reflected a kind of pressure or trend in cultivated land conversion.

In order to protect food production, when regional CLID value was high, the region should be paid more attention by people. The macroscopic decisions of land use planning formulated by government departments could regulate CLID value, and affect food production through the agricultural activity of farmers. Although there were many factors to affect the effect of model calculation, but more than half transformations of the agricultural land were selected by the model, so the model still had a great significance for the macro planning and decision. And the model also passed the inspection of Fuzzy kappa, it indicated that the model was stable and reliable.

3.6 Relationship Between CLID and Security of Cultivated Land in Small and Medium-Sized Cities

Due to the influence of urbanization, the agricultural land area in Zhangjiagang city had greatly reduced, but the decreasing speed of cultivated land area in different region were different. During 2004 and 2008, the decreasing speed of cultivated land in Yangshe town, Jingang town and Nanfeng town were 5.60, 3.25 and 3.01 ha per year respectively, and the speed was faster than that of other regions in Zhangjiagang. The results of model operation showed that CLID values of cultivated land cell in the above three regions were higher than other regions. The reason was that YangShe town was the location of Zhangjiagang city, in 2004, 29.4 % population of Zhangjiagang lived in this region, and Jingang town and jingang town were industrial center of Zhangjiagang city, the GDP of Jingang town and jingang town in 2004 was 42.7 % among whole GDP of Zhangjiagang city. On the other hand, the CLID value of arable land in Changyinsha region was the lowest, during 2004 and 2008, the decreasing speed of cultivated land in this region was the slowest too, and it was 0.34 ha per year. The reason was that the region was far away from downtown of Zhangjiagang, and the land use policy in this region was land conservation policy.

The quantitative and qualitative analysis of cultivated land stability, on the one hand, could evaluate the effectiveness of policies in current land conservation, on the other hand, could guide agricultural production behavior of farmers (Li et al. 2009). While the spatial heterogeneity of CLID was known, the different planning policies could be formulated in different regions, and the resources could be used more effectively.

3.7 Productivity of Cultivated Land and Food Security

With the acceleration of urbanization and continuous adjustment of industrial structure, the area of cultivated land in Zhangjiagang had decreased constantly. From 1996 to 2008, Zhangjiagang had reduced 10846.67 ha of farmland, and during the period, 2,200 ha of farmland had been increased by the reclamation and regulation and agricultural industrial structure adjustment, so the cumulative net reduction of cultivated land was 8646.67 ha. And the population of the city had increased year by year, in 1996, there was 828.9 thousand registered population. In 2008, there was 897.3 thousand registered population, and 68.4 thousand population had increased during the period. Cultivated land area per capita had decreased year by year.

Although the area of cultivated land in Zhangjiagang city had decreased constantly in recent years, but due to intensive management, scientific management and farming, the crop yield per area had gradually improved, so the total grain output had no influence obviously by decreasing cultivated land, and it could still meet the needs of the population in Zhangjiagang city.

3.8 Reasons for Agricultural Deficit in Zhangjiagang

First of all, increasing production, consumption and improved standard of living lead to the increase of agricultural ecologic footprint. In recent years, with the development of urbanization and economic level, the demands for industrial raw materials and agricultural produce have increased a lot, which triggers the increase of ecological footprint and agricultural ecological deficit. The consumption of animal meat, milk, and eggs is increasing at a high rate, which requires large pieces of grassland to be produced. However, Zhangjiagang is very short of grassland, so the ecological deficit of grassland contributes to the high level of agricultural deficit in this area.

Second, overpopulation and decreased cultivated land lead to the low level of bearing capacity of agricultural ecology, and thus the contradiction between population and farmland is more highlighted. On the one hand, the expanding city, widen streets and spacious workshops take up large pieces of farmland; on the other hand, being short of systematic coordinated city planning, the scattered industrial distribution consumes much land, which results in the waste of land resources and low efficiency of land use (Tang et al. 2007).

4 Conclusion

The integration of the natural – geographic factors and social – economic impact factors into the cellular automaton model could analyze the instable state of cultivated land better in Zhangjiagang city. The inputting parameters of the model could be obtained easily, and the operation was less complex. So the model could be used to study the productivity of regional land.

The CLID values of Zhangjiagang had obvious spatial heterogeneity. The results of model operation showed that the area of highest CLID values in Zhangjiagang distributed in Yangshe town, Jingang town and Nanfeng town, their average CLID values were 37.90, 33.95 and 34.5 respectively, and the area with higher CLID value in Yangshe town was the largest. The minimum CLID value was in Changyinsha region, and it was 14.18. In addition, there was a certain correlation between CLID value and reducing speed of cultivated land in Zhangjiagang city.

The change of total grain output achieved from remote sensing data and the condition of population growth in Zhangjiagang could estimate that the impact of urbanization development on local food safety was not obvious, food supplies of Zhangjiagang city could meet the needs of the local population.

Through a series of measures including reforming and improving land system, reasonable planning urban development, arranging non-agricultural land, strengthening protection consciousness and propaganda of farmland, improving agricultural production conditions and developing efficient agriculture, the agricultural ecological deficit could probably be reduced, and the food security could be ensured, and the sustainable development of the city would be finally realized.

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