# Removing Bottlenecks in Fertilizing Salt-Affected Soils for Agricultural Production

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**Abstract**

A large extent of salt-affected land in the world provides both challenge and opportunity to bolster food security and sequester carbon after reclamation. Sustainable management of salt-affected soil for productive agriculture is a key to the prosperity of farmers in these areas. It also boosts expensive initiatives to further reclaim severely affected salty lands currently lying barren. Managing fertility of salt-affected lands sustainably requires persistent efforts in maintaining good soil health. Good soil health presents minimum damage to an ecosystem without affecting its services. Maintaining good soil health guarantees flushing of excess salts from soil, proper hydraulic functions of soil profile, and sufficient and timely availability of nutrients for plant growth. These characteristics favor good plant growth and productivity under salt-affected environments. Based on long-term research experiments, a set of six principles to sustainably manage salt-affected soils for agricultural use is proposed here. The principles address the issues encountered in managing fertility in salt-affected areas in general and also hold good in general for crop fertility management. These principles address resource and energy conservation issues, nutrient budgeting, precision application, environmental losses, and economics of soil fertility management for productive agriculture.

## Importance of Soil Health

Soil is a complex system which is made up of multiple components and is multifunctional with definite operating limits and a characteristic spatial configuration (Kibblewhite et al. 2008). It is an important and essential component for agricultural production and environmental quality at global level (Glanz 1995). Deterioration of soil fertility is causing threat to soil quality and

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**Table 1** Potential indicators of soil quality

| Physical | Chemical | Biological |
|---|---|---|
| Soil type | Optimal pH[a] | Organic matter |
| Aggregation and structure[a] | Nutrient holding capacity | Microbial biomass[a] |
| Aeration and compaction | CEC[a] | Diversity, i.e., macro- and microfauna |
| | Soluble salts | Roots |
| Water infiltration and retention[a] | Redox potential | Nutrient cycling[a] |
| Surface sealing[b] | Nutrient availability[a] | Low pest numbers |
| Soil stability[a] | Low level of toxicity | Ability to suppress disease |

[a] Suggested as soil quality indicators by Bhardwaj et al. (2011)

[b] Suggested as important parameter related to clay mineralogy by Bhardwaj et al. (2010)

sustainable development of agriculture. Soil quality is an integrative indicator of environmental quality, (NRC 1993; Monreal et al. 1998), food security (Lal 1999), and economic viability (Hillel 1991), and hence it is an unignorable aspect by any consideration. A soil with proper availability and discharge of water, good biological activity, and plenty of nutrient supply is regarded as that of good health (Table 1). The Soil Science Society of America (1997) has defined soil quality as “The capacity of a specific kind of soil to function within natural or managed ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health.” Sustenance of good soil quality is challenging yet necessary in the present scenario of intensive agriculture and fast economic development (Doran and Parkin 1996). With the growing food demand, no doubt, intensive agriculture has increased the food production, yet, at the same time, it has led to nutrient imbalance, particularly micronutrients, unnecessary fertilization, soil pollution, water-related problems, and decreased soil health. These activities have caused second-generation problems with the mining of 10 million tons of nutrient per year, leaving soil in a condition of nutrient deficiency, decreased carbon accumulation, and impaired soil health. Increasing population and increased load on exhausting resources and decreasing environmental quality have threatened those naturally occurring processes that endure the life on earth (Costanza et al. 1992; Postel 1994). Thus, soil health is an integrative property of soil and is very sensitive to agricultural activities, crop production, and ecology of the system. Therefore, it is highly relevant to sustainable agriculture. In ecology, soil health is defined as the relationships of biological interactions, nutrient cycling, organic matter assimilation, and/or plant-animal interaction (Johnston and Crossley 2002). Such processes are highly sensitive to frequency and intensity of agricultural interventions that have significant effect on soil physicochemical properties and ultimately the soil health.

Conventional agricultural practices like tillage operations, fertilizer use, cropping pattern, and other agronomic aspects have significant influence on soil and water quality. Soil management is crucial to all management practices carried out. Still, there are several reports suggesting degradation of agricultural soils due to erosion, loss of soil carbon and organic matter, soil compaction, increased salinity, and other related activities (European Commission 2002). Assessment of soil health and its quality is necessary to evaluate the degradation status and its severity with changing land use and management operations (Lal and Stewart 1995). Correlating soil health with the direction of change with time may be used as a pointer for any sustainable land management (Doran and Zeiss 2000; Karlen et al. 1997). Main responsible causes for degradation of soil health and soil quality in Asia are nutrient imbalance, excessive fertilization, soil pollution, and soil loss processes (Zhang et al. 1996; Hedlund et al. 2003). Deficiency of nitrogen, phosphorous, and potassium is more common worldwide and requires serious concern for soil management and fertility improvement.

Conventional management practices, viz., tillage, fertilizer use, and most importantly cropping pattern, have influenced soil and water quality. Besides, these activities also significantly affect the atmospheric equilibrium by affecting the gaseous flow of greenhouse gases like $CO_2$, $N_2O$, and $CH_4$ (Rolston et al. 1993; Mosier 1998). It is important to maintain the balance between various soil productivities, environmental quality, and plant health. To achieve this equilibrium, it is imperative to go for sustainable cultivation techniques. Thus, sustainable agriculture enhances environmental quality after long-term implementation, helps in the sustenance of economic viability of natural resources, and thereby improves the quality of farmer and society as a whole (Schaller 1990). It is generally used as an indicator to the soil capacity to sustain biological productivity by maintaining plant and animal health without hampering environmental quality (Doran and Zeiss 2000). Soil quality is directly linked with the management practices applied and other factors of ecosystems (Schoenholtz et al. 2000; Freckman and Virginia 1997). In general, the indicators for soil quality and health revolve around the physical, chemical, and biological properties defined in an ecosystem. Other criteria are sensitivity to management, climate, and accessibility to conservation specialists (Doran and Parkin 1996; Karlen et al. 2008; Dexter 2004).

## Essential Components of Healthy Soils

Soil component, in general, includes all those factors which have impact on soil health. As illustrated in Fig. 1, components ultimately affect the soil health and govern the ecosystem for its sustainability. Soil components are broadly classified into five components: soil minerals, soil organic matter, soil air, soil water, and soil organisms. Among the various components of soil, soil organic matter is defined as the most important component of soil. It is plant litter, debris, and humus on which microorganisms flourish. A soil rich in organic matter gives sufficient substrate to soil organisms to act upon. Soil microorganisms are responsible for organic matter decomposition and mineralization of nutrients contained in it. This is also a nature-provided way to remove all toxins and wastes from an ecosystem. However, this decomposition is dependent on various other factors such as soil moisture, temperature, pH, and quality of the substrate material of which the organic matter is made up (Lavelle et al. 1997). A soil rich in humus, mainly humic acid and fulvic acid, is congenially supportive to healthy plant growth and virtuous nutritional quality of the harvest (Pettit 2006). Soil organic matter has significant effect on soil pH and thus the soil structure. The soil structure results from the balance between compaction (by machine and soil weight) and buildup of soil aggregates by compaction or any other means of fauna and climate and breaking of aggregates due to tillage activities (Roger-Estrade et al. 2000). The process which is responsible for these aggregate functions like carbon transformation, nutrient cycling, and water retention properties is interlinked with the functions of soil organisms (Lavelle et al. 1997; Swift et al. 2004). Soil is also responsible for a number of environmental processes such as regulation of carbon, nitrogen, and sulfur fluxes which are maintained by decomposition of organic matter by soil microbes (Foster 1988). The size and distribution pattern of soil aggregates decides and regulates the transport and diffusion mechanism of gases (Powlson et al. 2001). Microbial

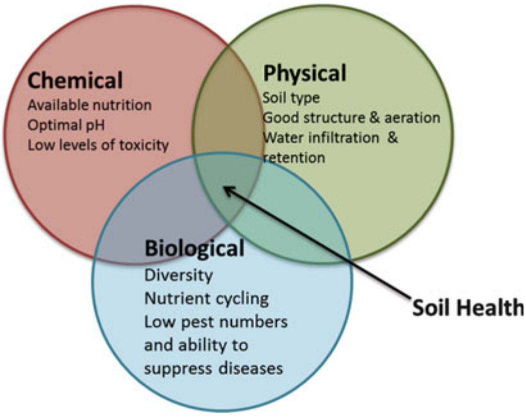


**Fig. 1** Physical, chemical, and biological components of a healthy soil

decomposers and other detritivores together regulate the rate of microbiological decomposition. They ensure release of nutrients and also have great influence on soil microbial population (Coleman and Hendrix 2000). Soil pH and amount of natural organic matter accumulated/incorporated at a given time are main governing factors for the continually occurring decomposition process.

## Salt-Affected Soils

The main sources of salt deposition/accumulation in soils are weathering, runoff water, and accession. However, in India, the problem of salt-affected land is generally irrigation induced, thus covering a large area over naturally occurring salt-affected soils. Salt-affected soils are either saline or sodic in nature. Saline soils refer to the soils having electrical conductivity more than 4 dS $m^{-1}$, whereas sodic soils are characterized by high exchangeable sodium percentage above 15. Based on FAO/UNESCO Soil Map of the World, a total of 831 Mha covering about 7–8 % of the surface area is suffering from this problem (FAO/AGL 2000). It is estimated that in India, about 6.75 Mha of land is barren or less productive due to being salt affected (Table 2), out of which 3.79 Mha is sodic and 2.96 Mha is saline (Mandal et al. 2010). This area is expected to increase due to canal irrigation that enhances the waterlogging and salinity of soil. Out of total affected area, 1.37 Mha land is spread over in Central Indo-Gangetic Plain (Uttar Pradesh). Besides geogenic development, salt-affected soils also result from changes in water balance with salt accumulation at surface or within the soil profile following the erosion and exposing it to the atmosphere (West et al. 1994).

Sodic soils have abundance of sodium carbonate, bicarbonate, and sulfate, which stimulate various kinds of processes in these soils. The soils usually show poor hydro-physical properties. Sodicity generates structural constraints in the soil that cause slaking and dispersion when the soil is wet and excessive hardness on drying. In the soil profile, the level of native soil organic matter is very less due to its high solubility, decomposability, and accessibility within the soil system (Tisdall and Oades 1982). As an adverse effect of poor soil physical and chemical conditions, the organic carbon

**Table 2** Extent of salt-affected soils (000 ha) in different states of India

| State | Saline soils | Sodic soils | Total |
|---|---|---|---|
| Andhra Pradesh | 77.6 | 196.6 | 274.2 |
| Andaman and Nicobar Islands | 77.0 | 0 | 77.0 |
| Bihar | 47.3 | 105.9 | 153.2 |
| Gujarat | 1680.6 | 541.4 | 2222.0 |
| Haryana | 49.2 | 183.4 | 232.6 |
| Jammu and Kashmir | 0 | 17.5 | 17.5 |
| Karnataka | 1.9 | 148.1 | 150.0 |
| Kerala | 20.0 | 0 | 20.0 |
| Madhya Pradesh | 0 | 139.7 | 139.7 |
| Maharashtra | 184.1 | 422.7 | 606.8 |
| Orissa | 147.1 | 0 | 147.1 |
| Punjab | 0 | 151.7 | 151.7 |
| Rajasthan | 195.6 | 179.4 | 375.0 |
| Tamil Nadu | 13.2 | 354.8 | 368.0 |
| Uttar Pradesh | 22.0 | 1347.0 | 1369.0 |
| West Bengal | 441.3 | 0 | 441.3 |
| Total | 2956.9 | 3788.2 | 6745.1 (say 6.75 Mha) |

Adapted from Mandal et al. (2010)

remains ≤1 gm $kg^{-1}$. Presence of high sodium on exchangeable sites directly affects the plant growth (Gupta and Abrol 1990). Presence of salts in the soil solution raises the osmotic potential of it and makes the water physiologically unavailable to the plants. This may further cause deficiency of several other essential micronutrients. At high pH, nitrogen volatilization also takes place at higher rates (Gupta and Abrol 1990; Grattan and Grieve 1999), while presence of chloride limits the uptake of nitrate (Grattan and Grieve 1999). All these activities cumulatively affect the plant growth and yield (Fig. 2) by affecting its physiological and biochemical functions (Lauchli and Epstein 1990; Rengasamy et al. 2003). However, the nature and severity depends on several other factors like topography, hydrology, drainage, land use, and climatic conditions (Yadav 2011). High sodicity causes high dispersion of soil as clay particles move apart and weaken the aggregate structure. This leads to soil structural collapse and closing of soil pores resulting in hard surface crusts. Presence of hard pan of calcium carbonate in the deeper root zone also restricts downward movement of both water and roots. These soils are characterized with high bulk density and very poor hydraulic conductivity. The sodic soils reduce the productive potential of arable lands to nearly one third of their capacity all over the world. However, the severity of the problem is dependent on several other factors as well.

## Health and Fertility Constraints in Salt-Affected Soils

Intensive agriculture, in the present scenario of increased industrialization and urbanization, has given rise to large-scale degradation to soil qual-

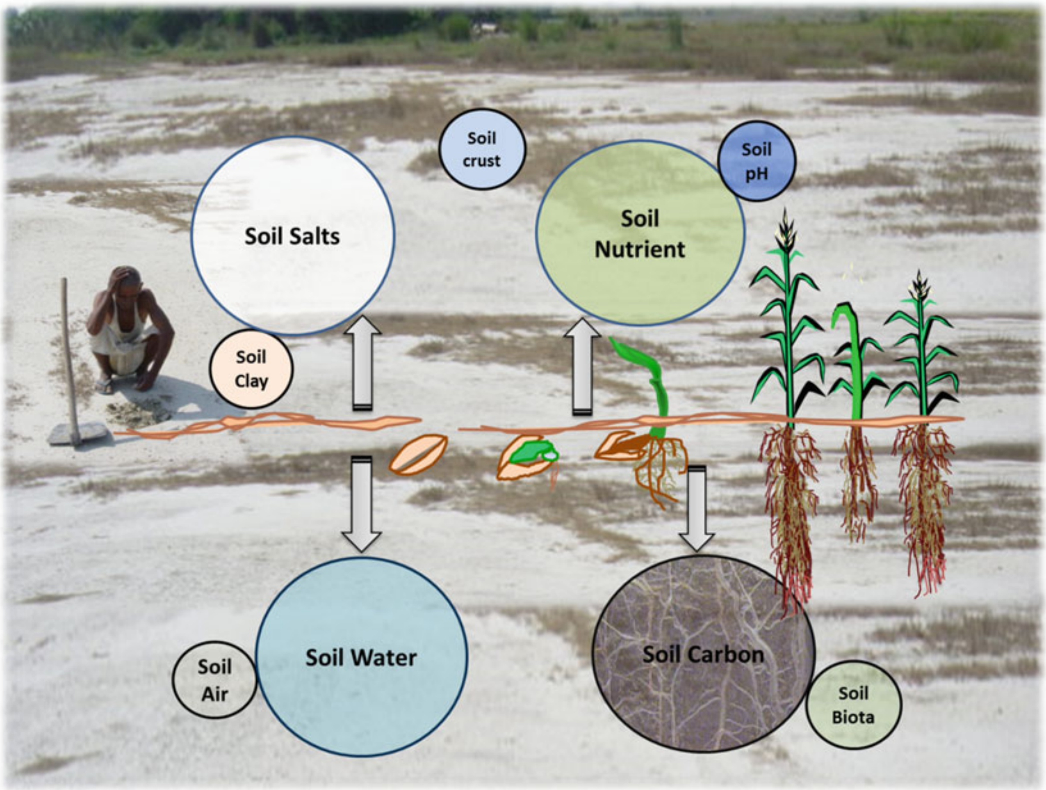


**Fig. 2** Multiple abiotic stresses in salt-affected soils

ity of highly productive areas. This was at its highest during green revolution period and even after that it continues to degrade the soil health. Injudicious exploration of resources from soil ecosystem has created the problem of soil salinity. Soil salinity brings the changes to soil structure and causes nutrient deficiencies. It has now become a menace, all across the world, which has severe effects on agricultural productivity and livelihood security. Farmers continue to explore the soil natural resources to fulfill their food and fiber needs. Conventional tillage practices and imprudent use of inorganic fertilizers have significant effect on functioning of soil system (Doran and Parkin 1996; Guerif et al. 2001). According to an estimate, about 5.6 mha area is salt affected out of the total of 8.6 mha (NRAA 2008) that is being developed in canal command areas. Salt accumulation is a threat to plant life. Sodic soils restrict the growth of plant and its productivity. Severity and nature of the effects of sodicity is also dependent on various other factors like topography, hydrology, climatic conditions, drainage restrictions, and land use (Yadav 2011). Salt-affected soils develop due to changes in water balance of the soil with excessive salt accumulation in soil profile that get exposed to the atmosphere after the erosion of the upper layer (West et al. 1994). The dispersion of clay particles results in formation of surface crusts, weakening of soil aggregates, and closing of soil pores which cause structural collapse.

Rice-wheat (RW) cultivation is a common and established cropping practice in India. The cultivation techniques used for RW system are very old. They cause deterioration of soil structure and influence the soil water relations. These cultivation practices leave the soil with poor physical condition for crop growth by limiting root development and its distribution (Sur et al. 1981; Boparai et al. 1992; Oussible et al. 1992). Rice is cultivated through wet cultivation method. Puddling activity done during this method reduces the water holding and transmission capacity of soil (Bhagat et al. 2003). Also flooding is maintained in field which causes loss of essential nutrients and decreases their availability to the plants due to the creation of anaerobic conditions. Flooding significantly affects the soil pH. Also, the process of nitrification-denitrification and phosphorous availability get influenced by the water stagnation particularly in oxisols, vertisols, and alluvial soils (Singh 2009). Iron and manganese toxicities with zinc are very common due to the prolonged submergence of soil (Neue and Lantin 1994; Savithri et al. 1999; Singh 2009). Decrease in zinc availability is an unescapable disorder of wetland rice which is very common in soils with high pH, high organic matter, high available P or Si content, and high Mg/Ca ratio apart from the soils with low level of zinc (Ponamperuma and Deturck 1993). Wheat sowing is a general practice after rice harvest which is commonly done by deep tilling of soil. Rice soil takes much time to attain the desired moisture level for tillage and sowing. This is the main reason for delay in wheat planting. Preparation of field for wheat sowing requires much time and energy, and if the seed is not planted within the desired tilth, it results in weak seedling growth and poor crop stand (Kumar et al. 2012). Delayed planting of wheat is also responsible for low productivity of wheat. Wheat germination, seedling development, crop establishment, and grain development are crucially temperature-dependent processes (Jame and Cutforth 2004). Thus, late-sown wheat tends to face temperature variations at different growth stages and get adversely affected. Shortening of the phyllochron interval (Cao and Moss 1994) and terminal heat stress during grain filling of wheat (Bashir et al. 2010; Farooq et al. 2011) are the common effects of temperature on wheat growth and its productivity. RW cropping system is highly nutrient exhaustive, and continuous cultivation causes depleted fertility of inherent soil by causing deficiency of several essential nutrients (Zia et al. 1997).

Increasing demand of food and fiber has forced the farmers to over-explore the natural resource of soil. For this, application of fertilizers is a widespread practice to increase the yield in India. Traditionally recommended dose of nitrogen (N), phosphorous (P), and potassium (K) is trial based and varies from field to field (Moody and Aitken 1996). Injudicious use of NPK fertilizers is detrimental to soil health (Carpenter et al. 1998) because it does not increase the nutrient uptake by plants (Smaling and Braun 1996). However, it contributes the low use efficiency of the excessively applied fertilizers and other associated factors of leaching, evaporation, and volatilization of nutrients (Tilman 1998; Gyaneshwar et al. 2002; Kennedy et al. 2004). Chemical fertilizers affect the salt solubility of soil and affect its pH of soil and soil structure by affecting soil aggregates. Variation in soil pH also influences the biological properties of soil that are ecologically important to maintain soil fertility. Alteration in soil health significantly alters the ecosystem capability of restoration of the damage. Sustainable development is, thus, the need of today's scenario that causes no or minimum damage to natural resources.

A good soil health represents minimum damage to the ecosystem without giving up its services. Soil quality is being conceptualized as an important linkage between the strategies of conservation management practices and achievement of the major goals of sustainable agriculture (Acton and Gregorich 1995; Parr et al. 1992). The processes that contribute significantly to the maintenance of the soil health include balanced nutrient flow, protected soil structure, and high activity of soil biological population. All this needs practices that are sustainable to operate and easy to maintain in practice.

## Six Principles of Effectively Managing Fertility of Salt-Affected Soils

### Principle 1: Thumb Rule, What Goes Out Should Come In

Intensive agriculture is causing overexploitation of the nutrients from soil. Continuous cropping of rice-wheat is also a reason for depletion in nutrient status of soil. The availability of any nutrient which is required and its interaction with other soil properties are vital to plant growth. A sustainable practice is required to maintain the equilibrium between the nutrient status of soil under continuous cropping and its physicochemical and biological properties. Maintenance of this equilibrium is also very essential for proper functioning of the soil ecosystem (Fig. 3). This helps in preserving soil organic carbon, physical properties and mineral structure of the soil, and also the soil biodiversity with the balance between soil pathogens and beneficial microbes.

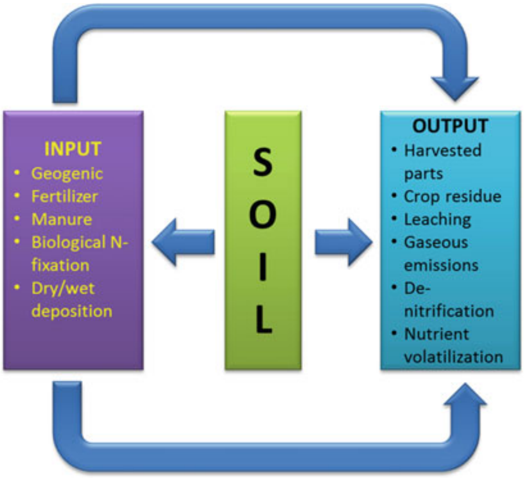


**Fig. 3** Equilibrium establishment between output and input of resources

The availability of required nutrients together with the degree of interaction between these nutrients and the soil plays a vital role in crop development. Understanding of the status of nutrients in soil, their removal, and resulting balance is important to fill the nutrient gap and preserve the soil health to ensure the food and nutritional security of present and future generations (Satyanarayana 2010). Balance between soil function for its productivity, environmental quality, and plant and animal health is crucial for optimal soil health.

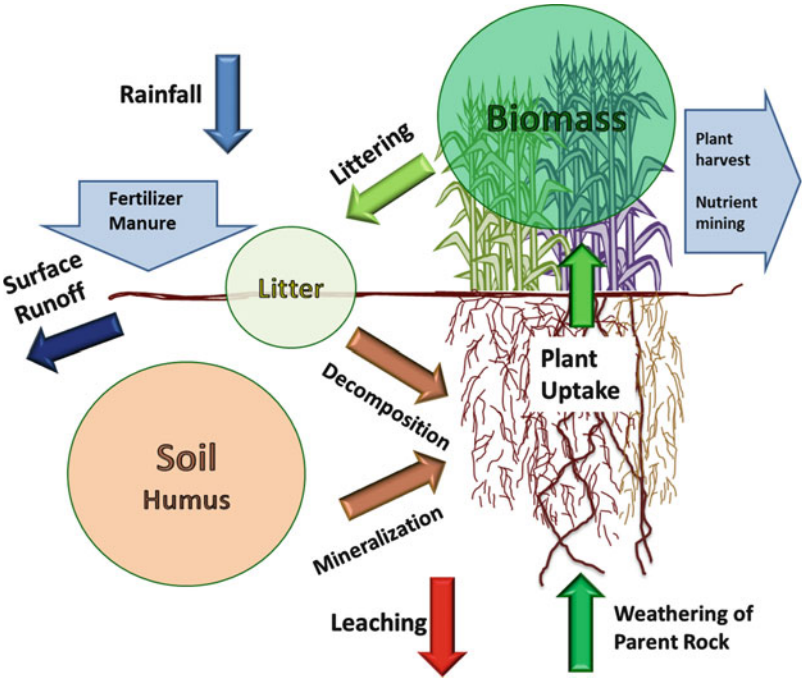
Soil organic matter plays a crucial role in maintaining/rebuilding the soil health as it is a continuous energy source to soil organisms. However, it is also getting depleted due to increased disturbance and overexploitation (Pettit 2006). Soil organisms help in maintaining good soil structure by converting organic matter to humus that remains cemented with clay particles. The clay-humus complex also helps substantially in transforming organic molecules into mineral elements that are readily available to plants. During the plowing and tilling activities, these cemented materials are broken down and provide greater surface area to microbes to act upon. Increasing organic matter input will increase the microbial activity and will increase the labile carbon pool of soil (Herrick and Wander 1998) by creating a positive impact on nutrient status and water infiltration properties of soil (Monreal et al. 1998). Implementation of techniques that are efficient in maintaining the balance between fertility buildup and fertility depletion status of soil is highly appreciated in the concept of sustainable agriculture. The influencing factors include recycling of crop residues, nutrient supply and retention by green manuring, composting, nitrogen fixation by legumes, crop rotation, intercropping, and reduced tillage (Kumwenda et al. 1996; Bruce et al. 2005; Jones 2006; Seis 2006). The ability of leguminous species for nitrogen fixation along with tree plantation is also a part of strategy to sustain soil fertility and reduce agricultural losses (Nair 1993; Sanchez and Leakey 1996; Dakora and Keyaz 1997). These practices significantly add carbon and nitrogen to the soil and enhance the microbial activities of soil. Reduced or zero-tillage systems are effective crop management practice that attains increased food production per unit area with improved natural resource use efficiency and without any significant damage to the environment.

## Principle 2: Adjusting the Nutrient Budget

Nutrient budgeting is an important consideration while managing the soil health and is becoming internationally recognized strategy for sustainable land management. It is well known that different agricultural activities cause loss of essential soil nutrients like N, P, and K. Nutrient budgeting covers all the factors that relate to the nutrient requirement of crops, nutrient status in soil, and also their concentration added through fertilizer application. Cultivated soils are prone to nutrient loss not only due to crop harvest but also because of some other environmental factors of soil erosion, runoff, and leaching. At the same time, mining of nutrients through cultivation is also not less significant (Sanchez and Leakey 1996). Quantitative knowledge of nutrient depletion is desirable to get an immediate idea about the trend of soil degradation. This will help in deriving the strategies for nutrient management in soil as it varies from soil to soil and crop to crop.

Nutrient input includes fertilizers, crop residues, organic manure, etc., whereas output includes nutrient removed as a plant harvest, grazing, emission loss, soil loss, etc., as shown in Fig. 4. To get a good soil health, the degradation of soil through nutrient loss must be replenished with nutrient supplementation in a planned manner (Subler and Uhl 1990; Nene 1996; Fischer and Vasseur 2000; Kwesiga et al. 2003). It involves intensive soil testing and matching it with the rate of nutrient application in chemical or organic form as per the requirement by the crop to be grown (O'Connor 1996). The use of available crop and soil models to calculate the nutrient levels in soil, leaching rate, uptake, and transformation has proved to be significant while planning for nutrient management (Bhardwaj and Srivastava 2013). Developing a fail-safe nutrient budgeting requires accurate data regarding nutrient input, its transformation or cycling, and output data, failure of which will imbalance the soil ecosystem as oversupplementation of nutrients without proper budgeting can also be a potential cause of increased nutrient loss. Thus, the accuracy of data estimation and assumptions is crucial for the accuracy of calculating nutrient budget. Correlation of nutrient budget with the data of soil and crop helps to study the nutrient cycle and thereby in calculating the optimum required dose of fertilizer for any crop and developing a nutrient management plan (Neeson 2001).

**Fig. 4** Export and import of essential nutrients in a soil ecosystem



## Principle 3: Regulation of Flows

Water management will play an important role in lowering the production risk associated with chemical fertilizer use. When the amount of irrigation water exceeds the crop requirement, it leaches down the root zone with nitrate, applied through fertilizers, causing soil and ground water pollution, particularly in developed countries (Conway and Pretty 1991; Bumb and Baanante 1996; NRC 1993). Water management, therefore, is an important part of nitrogen management in irrigation to prevent nitrate leaching. Fertigation, a common practice in modern agriculture (Papadopoulos 1988), involves the use of water-soluble fertilizers through sprinklers and drip. This method has been found to increase the yield of seed cotton up to 22 % and enhance water use efficiency as much as 93 %, based on dry matter yield (Janat and Somi 1997). The use of crop models in automation of irrigation scheduling would add to water and fertilizer use efficiency (El Moujabber and Bou Samra 2002). Poor drainage also causes associated problems of waterlogging, salinity, and toxicity, leading to water pollution mainly due to inappropriate irrigation. About 24 % of irrigated lands have been affected with salinity problems.

In semiarid areas, nutrient inputs need to be planned in combination with water harvesting and conservation plans (Dudal 2002). Adopting a zero-tillage cultivation practice with residue application helps in conserving soil moisture and prevents soil erosion (Kumar et al. 2012). Further, in the cracked soils in water-scarce areas, management of irrigation and soil plays an important role to reduce water losses (Islam and Weil 2000) as cracks do not get closed completely after rewetting, causing high loss of water which can be minimized using straw mulch by reducing evaporation from soil surface (Hundal and Tomar 1985). However, approaches toward conservation of soil moisture like use of crop residue (Fig. 5) and organic manure and development of water conservation strategies require exploring of the potential of agronomic practice for fertilizer use (Dembele and Savadogo 1996). Increasing the water use efficiency, particularly for rice-based yielding systems, using crop management techniques

**Fig. 5** Retention of crop residues in crop rotation enhances soil quality (Bhardwaj et al. 2011)

with emphasis on irrigation technologies, needs to be dealt with in combination with genetic improvement (Tran 1994).

Although some problem caused by past irrigation management plans increased real capital cost for erection of new irrigation systems and environmental problems such as secondary salinization, it has reduced the inclination toward further irrigation investment (Rosegrant and Svendsen 1993; Rosegrant and Pingali 1994). But despite the problems, this area cannot be left ignored and needs attention for maintenance of soil health and improvement in crop production.

## Principle 4: Precision Application

Application of fertilizer should be aimed at using correct requirement dose depending upon the crop need and also on agroclimatic conditions. Finding the appropriate dose and area of fertilizer use before its application would make it cost effective and help in enhancing the productivity. For this, it is essential to assess the soil quality keeping in view the degradation status and its trend, caused by various interventions of land use and planning (Lal and Stewart 1995). Evaluation of soil quality with a review of soil genesis before making any implementation of plan is important for the success of any scheme. The assessment of soil quality will help in planning the nutrient management plans on short- and long-term basis. Soil quality is indexed using different abiotic or biotic tests. Abiotic tests include analysis of physicochemical characteristics of soil such as pH, CEC, organic matter content, and nutrient status. Biotic tests comprise community composition of functionally important groups of organisms that indicate the health of soil system (Kibblewhite et al. 2008). The challenge involved in this is to develop the standards for assessing the changes that should be realistic, approachable, and of use to the farmers (Barrios and Trejo 2003). It is also necessary for farmers to develop knowledge about the organic fertilizers, use of advanced pest management techniques, and adopting high-yielding crop varieties with adequate water supply (Kumwenda et al. 1996).

Identification of problematic areas helps in monitoring the changes required in agricultural management plan to raise a sustainable and environment-friendly practice and provide assistance to government agencies in formulating and implementing land use policies (Granatstein and

Bezdicek 1992). However, periodic observations are essential to identify the status of soil at different stages after implementation of management plant to enhance its efficiency management (Karlen et al. 2008). This is for the reason that soil properties are sensitive factors in the implementation of management plans (Brejda et al. 2000). Lands facing problems of waterlogging, erosion, and high water table should be left without nutrient application so as to minimize the wastage of fertilizers.

## Principle 5: Timing the Application

Apart from the selection of the area to be brought under judicious use of fertilizers, timing of application also plays an important and effective role in enhancing the yield potential of crop and efficiency of management practice. It is aimed to enhance the use efficiency by the crop raised (VDCR 2005). Application of fertilizers, particularly N supplied in splits, has been found to be highly effective for crop rather than supplying them in a single application. Management of irrigation schedule with fertilizer supply has also proved to be an effective strategy (Fig. 6). Avoiding the application of fertilizers prior to heavy rainfall or irrigation would result in prevention of wastage from leaching.

## Principle 6: Economics and Environmental Considerations

Profitability of any applied input is assessed in terms of cost-benefit analysis. Hence, nutrient management plans should invariably include economic consideration taking account of cost and savings. Farmers may get higher yield after fertilizer application, but increased yield may have less market value in terms of cost-benefit ratio. A practice may be economically viable but may enhance the nutrient discharge into the environment, but a plan based on soil test-based recommendations may be more cost effective. Soil test data may help in development of a management plan and also for the improvement of plant and soil health. Deciding the fertilizer dose according to the plant requirement also trims down the input cost and causes minimum damage to the ecosystem. The use of organic fertilizer sources in combination with inorganic fertilizers or changing the cropping pattern not only rationalizes the input cost but has also been found to improve soil health. Switching to rice-lentil or rice-wheat-mung bean system gave higher initial profit, but rice-wheat-*Sesbania* system was found profitable in the long run with positive effect in soil health (Ali et al. 2012). These considerations may help ecosystem restoration as well as in raising income of the poor

**Fig. 6** Management of irrigation schedule with fertilizer application improves nutrient use efficiency (In frame: Management of fertilizer with low energy water application (LEWA) method resulted in enhanced nutrient availability as monitored using ion exchange resin strips)

**Fig. 7** No-till planting of wheat after rice harvest

people and contribute to social and economic development (UN 2003). Adaptation of zero-tillage technology (Fig. 7) is not only a time-saving technique but also an energy-saving as well as eco-friendly technique as it reduces the emission of greenhouse gases (Smith et al. 1998; Chauhan et al. 2000) Crop yields under zero tillage may be equivalent or little less than those of conventional practice, but it is cost effective as it lowers the cost of cultivation (Singh and Kaur 2012).

Conversely, a nutrient management plan may have a conflict between economic and environmental issues related to soil health (Rapport et al. 1997). Supplementation of essential nutrients to the plants may increase their entry to system and alter the equilibrium of soil ecosystem. Thus, any nutrient management plan should have socioeconomic impact in consideration before its implementation. Educating people about the site-specific soil quality will help in maintaining the socioeconomic benefits of a management plan, as it would help in understanding the plan and minimizing the loss of resources as well. However, the assessment of input and output cost, whether in terms of resources or financially, is important to evaluate the sustainability of any practice and will increase our dependency on using renewable sources (Doran and Zeiss 2000).

## Conclusion

Soil ecosystem provides a range of services to human beings. But over-exploitation of the related natural resources is causing depletion in the fertility and health aspects of soil. Conventional practices of tillage and irrigation are having deteriorating effects on soil structure and health. Shifting toward zero tillage and conservation tillage has been found to have favorable effects on aggregate stability, soil organic matter content, and moisture conservation. These practices also decrease fluctuation in soil temperature, reduce the risks of soil erosion, and enhance the activities of living organisms of soil. Basic idea behind this is to maintain the balance between output and input in soil ecosystem. Continuous use of inorganic fertilizers may cause decline in soil health and crop yields. Integrating nutrient management plan is an economically and ecologically friendly program that uses organic fertilizers like compost and other organic manures with inorganic fertilizers in an integrated manner to sustain high productivity.

Computation of nutrient budget to decide the quantity of fertilizer to be applied has come up as an economically and ecologically successful strategy in reducing fertilizer loss. Assessment of soil quality for finding the area of nutrient deficiency needs to be adopted on priority basis. This would serve as an indicator of soil health when planning for integrated and sustainable land management. Targeted, efficient, and adequate application of fertilizers is necessary to maximize their potential of influencing crop yield and minimizing the environmental pollution. All these plans need to be supported through proper policies, processes, and responsible bodies for implementing them practically.

## References

Acton DF, Gregorich LJ (1995) The health of our soils: toward sustainable agriculture in Canada. Agriculture Agri-Food Canada, CDR Unit, Ottawa

Ali RI, Awan TH, Ahmad M, Saleem MU, Akhtar M (2012) Diversification of rice-based cropping systems to improve soil fertility, sustainable productivity and economics. J Anim Plant Sci 22(1):108–112

Barrios E, Trejo MT (2003) Implications of local soil knowledge for integrated soil management in Latin America. Geoderma 111(3):217–231

Bashir MU, Akbar N, Iqbal A, Zaman H (2010) Effect of different sowing dates on yield and yield components of direct seeded coarse rice (*Oryza sativa* L). Pak J Agric Sci 47:361–365

Bhagat RM, Bhardwaj AK, Sharma PK (2003) Long term effect of residue management on soil physical properties, water use and yield of rice in north-western India. J Indian Soc Soil Sci 51(2):111–117

Bhardwaj AK, Srivastava S (2013) Managing soil health and fertility in rice-wheat cropping systems using participatory approaches. In: Singh YP, Mishra VK, Sharma DK, Singh AK (eds) Participatory approaches to enhance farm productivity of salt affected soils. Central Soil Salinity Research Institute, Regional Research Station, Lucknow, pp 42–63

Bhardwaj AK, McLaughlin RA, Levy GJ (2010) Depositional seals in polyacrylamide-amended soils of varying clay mineralogy and texture. J Soils Sediments 10:494–504

Bhardwaj AK, Jasrotia P, Hamilton SK, Robertson GP (2011) Ecological management of intensively cropped agro-ecosystems improves soil quality with sustained productivity. Agric Ecosyst Environ 140:419–429

Boparai BS, Singh Y, Sharma BD (1992) Effect of green manuring with *Sesbania aculeata* on physical properties of soil and on growth of wheat in rice–wheat and maize–wheat cropping systems in semiarid regions of India. Arid Soil Res Rehabil 6:135–143

Brejda JJ, Karlen DL, Smith JL, Allan DL (2000) Identification of regional soil quality factors and indicators II. Northern Mississippi Loess Hills and Palouse Prairie. Soil Sci Soc Am J 64(6):2125–2135

Bruce S, Howden S, Graham S, Seis C, Ash J, Nicholls A (2005) Pasture cropping: effects on biomass, total cover, soil water and nitrogen. Grassland conservation and production: both sides of the fence. Proceedings of the 4th Stipa conference on management of native grasses and pastures, Burra, SA, 11–13 October, pp 141–147

Bumb BL, Baanante CA (1996) The role of fertilizer in sustaining food security and protecting the environment to 2020. International Food Policy Research Institute, Washington, DC, USA

Cao W, Moss DN (1994) Sensitivity of winter wheat phyllochron to environmental changes. J Agron 86:63–66

Carpenter SRNF, Caraco DL, Correll RW, Sharpley ANH, SmithV H (1998) Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol Appl 8:559–568

Chauhan DS, Sharma RK, Tripathi SC, Kharub AS, Chokar RS (2000) Wheat cultivation after rice- a paradigm shift in tillage technology. Indian Farming 50:21–22 and 38

Coleman DC, Hendrix PF (2000) Invertebrates as webmasters in ecosystems. CAB International, Wallingford

Conway GR, Pretty JN (1991) Unwelcome harvest: agriculture and pollution. Earthscan Publications Ltd., London

Costanza R, Norton BG, Haskell BD (1992) Ecosystem health: new goals for environmental management. Island Press, Washington, DC

Dakora FD, Keyaz SO (1997) Contribution of legume nitrogen fixation to sustainable agriculture in sub-Saharan Africa. Soil Biol Biochem 29:809–817

Dembele NN, Savadogo K (1996) The need to link soil fertility management to input/output market development in West Africa: key issues. Paper presented at the IFDC seminar on “Linking soil fertility management to agricultural input and output market development: The key to sustainable agriculture in West Africa”, Lomé, November 19–22, 1996

Dexter AR (2004) Soil physical quality – Part I. Theory, effects of soil texture, density, and organic matter, and effects on root growth. Geoderma 120:201–214

Doran JW, Parkin TB (1996) Quantitative indicators of soil quality: a minimum data set. In: Doran JW, Jones AJ (eds) Methods for assessing soil quality, vol 49, Soil Science Society of America. Special Publication, Madison, pp 25–37

Doran JW, Zeiss MR (2000) Soil health and sustainability: managing the biotic component of soil quality. Appl Soil Ecol 15:3–11

Dudal R (2002) Forty years of soil fertility work in Sub-Saharan Africa. In: Vanlauwe B, Diels J, Sanginga N, Merckx R (eds) Integrated plant nutrient management in sub-Saharan Africa. CAB International, Wallingford, pp 7–21

El Moujabber M, Bou Samra B (2002) Assessment of groundwater salination by seawater intrusion in a typical horticultural area. Acta Horticult 573:195–202

European Commission (2002) Communication of 16 April 2002 from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions: towards a thematic strategy for soil protection [COM (2002) 179 final]. European Commission, Brussels

FAO/AGL (2000) Extent and causes of salt-affected soils in participating countries. FAO/AGL-Global network on integrated soil management for sustainable use of salt-affected lands. http://www.fao.org/ag/agl/agll/spush/topic2.htm

Farooq M, Bramley H, Palta JA, Siddique KHM (2011) Heat stress in wheat during reproductive and grain filling phases. Crit Rev Plant Sci 30:491–507

Fischer A, Vasseur L (2000) The crisis in shifting cultivation practices and the promise of agroforestry: a review of the Panamanian experience. Biodivers Conserv 9:739–756

Foster RC (1988) Microenvironments of soil microorganisms. Biol Fertil Soils 6:189–203

Freckman DW, Virginia RA (1997) Low-diversity Antarctic soil nematode communities: distribution and response to disturbance. Ecology 78:363–369

Glanz JT (1995) Saving our soil: solutions for sustaining Earth's vital resource. Johnson Books, Boulder

Granatstein D, Bezdicek DF (1992) The need for a soil quality index: local and regional perspectives. Am J Altern Agric 7:12–16

Grattan SR, Grieve CM (1999) Mineral nutrient acquisition and response by plants grown in saline environments. In: Pessarakli M (ed) Handbook of plant and crop stress, 2nd edn. Marcel Dekker, New York, pp 203–230, Ch 9

Guerif J, Richard G, Dürr C, Machete JM, Recous S, Roger-Estrade J (2001) A review of tillage effects on crop residue management, seedbed conditions and seedling establishment. Soil Tillage Res 61:13–32

Gupta RK, Abrol IP (1990) Salt affected soils— their reclamation and management for crop production. Adv Soil Sci 12:223–275

Gyaneshwar P, Kumar NJ, Pareka LJ, Podle PS (2002) Role of soil microorganisms in improving P nutrition of plants. Plant Soil 245(1):83–93

Hedlund A, Witter E, An BX (2003) Assessment of N, P and K management by nutrient balances and flows on peri-urban smallholder farms in southern Vietnam. Eur J Agron 20:71–87

Herrick JE, Wander MM (1998) Relationships between soil organic carbon and soil quality in cropped and rangeland soils: the importance of distribution, composition and soil biological activity. In: Lal R, Kimble J, Follett J, Steward BA (eds) Advances in soil science: soil processes and the carbon cycle. CRC Press, Boca Raton, pp 405–425

Hillel D (1991) Out of the earth: civilization and the life of the soil. University of California Press, Berkeley, 321 pp

Hundal SS, Tomar VS (1985) Soil-water management in rainfed rice-based cropping systems. International Rice Research Institute, Los Banos, pp 337–349

Islam KR, Weil RR (2000) Soil quality indicator properties in mid-Atlantic soils as influenced by conservation management. J Soil Water Conserv (Ankeny) 55(1):69–78

Jame YW, Cutforth HW (2004) Simulating the effects of temperature and seeding depth on germination and emergence of spring wheat. Agric For Meteorol 124:207–218

Janat M, Somi G (1997) Comparative study of nitrogen fertilizer use efficiency of cotton crop under conventional and fertigation practices using 15N methodology. TCP, Raw/5/002. Annual coordination meeting. Beirut, November 1997

Johnston JM, Crossley DA (2002) Forest ecosystem recovery in the southeast US: soil ecology as an essential component of ecosystem management. For Ecol Manage 155:187–203

Jones CE (2006) Carbon stops salt. Aust Farm J. http://carbonandsalt.blogspot.com/

Karlen DL, Mausbach MJ, Doran JW, Cline RG, Harris RF, Schuman GE (1997) Soil quality: a concept, definition, and framework for evaluation. Soil Sci Soc Am J 61:4–10

Karlen DL, Andrews SS, Wienhold BJ, Zobeck TM (2008) Soil quality assessment: past, present and future. J Integr Biosci 6(1):3–14

Kennedy IR, Choudhury ATMA, Kecskes ML (2004) Non-symbiotic bacteria diazotrophs in crop-farming systems: can their potential for plant growth promotion be better exploited? Soil Biol Biochem 36:1229–1244

Kibblewhite MG, Ritz R, Swift MJ (2008) Soil health in agricultural systems. Phil Trans R Soc B 363:685–701. doi:10.1098/rstb.2007.2178

Kumar S, Sharma PK, Anderson SH, Saroch K (2012) Tillage and rice-wheat cropping sequence influences on some soil physical properties and wheat yield under water deficit conditions. Open J Soil Sci 2:71–81. doi:10.4236/ojss.2012.22011

Kumwenda JDT, Waddington SR, Snapp SS, Jones RB, Blackie MJ (1996) Soil fertility management research for the maize cropping systems of smallholders in southern Africa: a review, Natural Resources Group paper 96-02. International Maize and Wheat Improvement Center (CIMMYT), Mexico City

Kwesiga FR, Akinnifesi FK, Mafongoya PL, McDermott MH, Agumya A (2003) Agroforestry research and development in southern Africa during the 1990s: review and challenges ahead. Agrofor Syst 59:173–186

Lal R (1999) Soil quality and food security: the global perspective. In: Lal R (ed) Soil quality and soil erosion. CRC Press, Boca Raton, pp 3–16

Lal R, Stewart BA (1995) Soil management: experimental basis for sustainability and environmental quality. Advances in soil science. CRC Press, Boca Raton

Lauchli A, Epstein E (1990) Plant responses to saline and sodic conditions. In: Tanji KK (ed) Agricultural salinity assessment and management. ASCE manuals and reports on engineering practice, vol 71. ASCE, New York, pp 113–137

Lavelle P, Bignell D, Lepage M, Wolters V, Roger P, Ineson P, Heal OW, Dhillion S (1997) Soil function in a changing world: the role of invertebrate ecosystem engineers. Eur J Soil Biol 33:159–193

Mandal AK, Sharma RC, Singh G, Dagar JC (2010) Computerized database on salt affected soils in India, Technical bulletin no. 2/2010. Central Soil Salinity Research Institute, Karnal, p 28

Monreal CM, Dinel H, Schnitzer M, Gamble DS, Biederbeck VO (1998) Impact of carbon sequestration on functional indicators of soil quality as influenced by management in sustainable agriculture. In: Lal R, Kimble JM, Follett RF, Stewart BA (eds) Soil processes and the carbon cycle. CRC Press, Boca Raton, pp 435–457

Moody PW, Aitken RL (1996) Fertiliser management in tropical horticulture: is it sustainable? In Proceedings of the third Australian Society of Horticultural Science and the first Australian Macadamia Society Research conference. Broadbeach, Queensland

Mosier AR (1998) Soil processes and global change. Biol Fertil Soils 27:221–229

Nair PKR (1993) The history of agroforestry. In: An introduction to agroforestry. Kluwer Academic Publishers, Dordrecht, pp 3–11

Nene YL (1996) Sustainable agriculture: future hope for developing countries. Can J Plant Pathol 18:133–140

Neue HU, Lantin KS (1994) Micronutrient toxicities and deficiencies in rice. In: Yeo AR, Flowers TJ (eds) Monographic theories of applied genetics, vol 21. Springer, Berlin/Heidelberg, pp 175–200

NRAA (2008) Harmonization of wastelands/degraded land datasets of India. National Rainfed Area Authority (NRAA), Ministry of Agriculture, Government of India, New Delhi, 5 pp

NRC (1993) Soil and water quality: an agenda for agriculture. National Research Council (NRC), National Academy Press, Washington, DC

O'Connor GA (1996) Organic compounds in sludge-amended soils and their potential for uptake by crop plants. Sci Total Environ 185(1):71–81

Oussible M, Crookstan RK, Larson WE (1992) Subsurface compaction reduced root and shoot growth and grain yield of wheat. J Agron 84:34–38

Papadopoulos GM (1988) Implementation of a general purpose dataflow multiprocessor. Doctoral dissertation, Massachusetts Institute of Technology

Parr JF, Papendick RI, Hornick SB, Meyer RE (1992) Soil quality: attributes and relationship to alternative and sustainable agriculture. Am J Altern Agric 7:5–11

Pettit RE (2006) The wonderful world of humus and carbon. Accessed at: http://humusandcarbon.blogspot.com/

Ponnamperuma FN, Deturck P (1993) A review of fertilization in rice production. Int Rice Comm Newsl 42:1–12

Postel S (1994) Carrying capacity: Earth's bottom line. In: State of the world. World watch institute report on progress towards a sustainable Society. W.W. Norton & Company, New York, 265 p, ISBN 0-393-31117-1. pp 3–21

Powlson David S, Hirsch Penny R, Brookes Philip C (2001) The role of soil microorganisms in soil organic matter conservation in the tropics. Nutr Cycl Agroecosyst 61:41–51

Rapport DJ, McCullum J, Miller MH (1997) Soil health: its relationship to ecosystem health. In: Pankhurst CE, Doube BM, Gupta VVSR (eds) Biological indicators of soil health. CAB International, Wallingford, pp 29–47

Rengasamy P, Chittleborough D, Helyar K (2003) Root-zone constraints and plant-based solutions for dryland salinity. Plant Soil 257:249–260

Roger-Estrade J, Richard G, Manichon H (2000) A compartmental model to stimulate temporal changes in soil structure under two cropping systems with annual mould board ploughing in a silt loam. Soil Tillage Res 54:41–53

Rolston DE, Harper LA, Mosier AR, Duxbury JM (1993) Agricultural ecosystem effects on trace gases and global climate change, vol 55, American Society of Agronomy. Special Publication, Madison

Rosegrant MW, Pingali PL (1994) Policy and technology for rice productivity growth in Asia. J Int Dev 6 (6):665–688

Rosegrant MW, Svendsen M (1993) Asian food production in the 1990s: irrigation investment and management policy. Food Policy 18(1):13–32

Sanchez Pedro A, Leakey Roger RB (1996) Land use transformation in Africa: three determinants for balancing food security with natural resource utilization. Keynote address. In: Proceedings of European Society of Agronomy 4th Congress, Velthoven, The Netherlands, July 7–11, 1996

Satyanarayana T (2010) State-wise approach to crop nutrient balances in India. In: Proceedings of the international conference on the role potassium balanced nutrition, OUAT, Bhubaneswar, Orissa, India

Savithri P, Perumal R, Nagarajan R (1999) Soil and crop management technologies for enhancing rice production under micronutrient constraints. Nutr Cycl Agroecosyst 53:83–93

Schaller N (1990) Mainstreaming low-input agriculture. J Soil Water Conserv 45:9–12

Schoenholtz SH, VanMiegroet H, Burger JA (2000) A review of chemical and physical properties as indicators of forest soil quality: challenges and opportunities. For Ecol Manage 138:335–356

Seis C (2006) Pasture-cropping: a land management technique. In: Proceedings 3rd OFA national organic conference, July 2006, Sydney, pp 59–61. http://www.winona.net.au

Singh AK (2009) Nutrient management in problem soils. In: Singh G, Qadar A, Yaduvanshi NPS, Dey P (eds) Enhancing nutrient use efficiency in problem soils. Central Soil Salinity Research Institute, Karnal, pp 1–21

Singh A, Kaur J (2012) Impact of conservation tillage on soil properties in rice-wheat cropping system. Agric Sci Res J 2(1):30–41

Smaling EMA, Braun AR (1996) Soil fertility research in sub-Saharan Africa: new dimensions, new challenges. Commun Soil Sci Plant Anal 27:365–386

Smith P, Powlson DS, Glendining MJ, Smith JU (1998) Preliminary estimates of the potential for carbon mitigating in European soils through no-till farming. Glob Chang Biol 4(6):679–685

Soil Science Society of America (1997) Glossary of soil science terms. Soil Science Society of America, Madison

Subler S, Uhl C (1990) Japanese agroforestry in Amazonia: a case study in Tome-Acu, Brazil. In: Alternatives to deforestation. Columbia University Press, Oxford, pp 152–166

Sur HS, Prihar SS, Jalota SK (1981) Effect of rice–wheat and maize–wheat rotations on water transmission and wheat root development in a sandy loam soil of Punjab, India. Soil Tillage Res 1:361–371

Swift MJ, Izac A, Van Noorwidjk M (2004) Biodiversity and ecosystem services in agricultural landscapes—are we asking the right questions? Agric Ecosyst Environ 104(1):113–134

Tilman D (1998) The greening of the green revolution. Nature 396:211–212. doi:10.1038/24254

Tisdall JM, Oades JM (1982) Organic matter and waters table aggregates in soil. J Soil Sci 33:141–163

Tran DV (1994) Major issues in Japonica rice production. In: Temperate rice conference – achievements and potential, Proceedings of the temperate rice conference, 21–24 February 1994, Yanco, New South Wales, Australia, vol 1. p 65–70

UN (2003) Halving global hunger. A background paper for the human development report by the Hunger Task Force (HTF) for the United Nation's Millennium Project. Springer, Berlin/Heidelberg

VDCR (2005) Virginia Department of Conservation and Recreation (VDCR), Division of Soil and Water Conservation. 2005. Virginia Nutrient Management Standards and Criteria. Springer, Berlin/Heidelberg, pp 96–107

West NE, Stark JM, Johnson DW, Abrams MM, Wright JR, Heggem D, Peck S (1994) Effects of climate change on the edaphic features of arid and semi-arid lands of western North America. Arid Soil Res Rehabil 8:307–351

Yadav JSP (2011) Overview of management of salt affected soils in India. In: Sharma DK, Rathore RS, Nayak AK, Mishra VK (eds) Sustainable management of sodic lands. Central Soil Salinity Research Institute, Regional Research Station, Lucknow, p 416

Zhang WL, Tian ZX, Zhang N, Li XQ (1996) Nitrate pollution of groundwater in northern China. Agric Ecosyst Environ 59:223–231

Zia MS, Ali A, Aslam M, Baig MB, Mann RA (1997) Fertility issues and fertilizer management in rice wheat system, vol 23, Farm management notes. FAO Reg. Off, Asia and Pacific, Bangkok