Chapter 50
Sustainable Agriculture Through Integrated Soil Fertility Management on Degraded Lands

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Abstract The use of natural resources to meet people's requirements, currently and in the future, is sustainable agriculture. In order to uphold the growing rural and urban population in the developing world, considerable development in the efficiency of agricultural systems is required. Intensification of current production systems via increasing cropping intensity and by increased use of external inputs is often the only way to increase agricultural production. However, a major portion of the currently cultivated land is being lost through soil degradation. Degradation includes soil erosion, nutrient depletion, desertification, deforestation, salinization and overgrazing. As agricultural areas become even more crowded, arable land has come under increasing pressure. Agricultural yields are at risk of serious decline as soils are becoming more degraded, putting the livelihoods of millions of subsistence farmers at risk. Integrated soil fertility management (ISFM) is the key in raising productivity levels while maintaining the natural resource base. The main purpose of this integrated approach is to restore soil nutrient pools, maximize on-farm recycling of nutrients, reduce nutrient losses to the environment and improve the efficiency of inputs. Soil fertility can be built up by progressive and steady modification of the natural resources including soils, vegetation and water by crop fallowing, grazing, selecting crop species, deep ploughing to break the plough pan, subsoiling, organic fertilizing, transferring crop residues and fodder. Therefore,

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ISFM is a viable tool to rebuild the degraded soils. Conclusively, ISFM can play a major role in improving farm output from degraded lands and ultimately in sustainable agriculture for the poor farmers.

Keywords Degraded land • Eroded soil • Nutrient • Soil fertility • Sustainable agriculture

50.1 Introduction

Land refers to soils, plants and water resources essentially required for crop production. Soil being the natural medium for growth provides air, water and anchorage to plants. It is also the hub of mineral nutrients required by plants for normal growth and development. Agricultural soils of the world are being intensively used to grow crops for human consumption. Soil, therefore, play a fundamental role in human food chain (Oliver 1997). However, non-judicious use of this precious natural resource has seriously deteriorated its quality and productivity. Deterioration of biophysical environment of land by human-induced processes resulting in reduced soil productivity is called land degradation (Dregne 2002). The main causes of land degradation are (1) intensive cultivation, (2) deforestation, (3) poor quality irrigation, (4) unbalanced fertilization and (5) industrialization. It is estimated that up to 40% of the world's total agricultural land is seriously degraded and 24% of the productive areas are under continuous degradation (Bai et al. 2008). According to the Land Degradation Assessment in Drylands (LADA 2010) project executed by FAO, apart from the increased cost of fertilizer, land degradation is costing about US$40 billion annually. However, losses are much more if cost of losing the biodiversity is also considered.

Highly degraded lands are found especially in semiarid areas (sub-Saharan Africa, Chili), areas with high population pressure (China, Mexico, India) and regions undergoing deforestation (Indonesia) (Fig. 50.1). Governments and scientists are trying to save the precious ecosystem for poor farmers who are totally dependent on these lands. At least now, the consensus has developed to judiciously use the land for continuous high productivity.

Sustainable increase in agricultural produce is a necessity to feed the ever growing population of the world. Sustainable agriculture assures human food and fibre needs, enhanced environmental quality, efficient use of nonrenewable and on-farm resources, and economic viability of farm operations and enhanced quality of life for farmers and for the society as a whole. Soil fertility degradation has been described as the second most important constraint to food security in Africa and other least developed countries (Swift and Shepherd 2007). Maintenance and improvement of soil fertility is an essential step towards sustainable agriculture. Application of inorganic fertilizers is still below their recommended rates in most of the developing countries. Thereby, application of mineral fertilizers will increase yields. However, their increasing costs, decreasing efficiencies and severe environmental impacts need to be addressed. Organic farming seems to be a sustainable

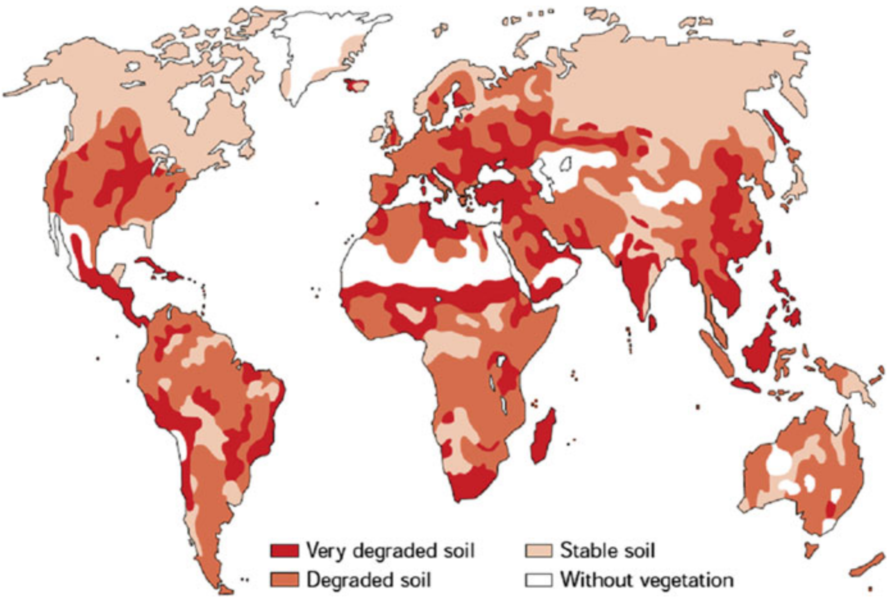

Fig. 50.1 Severity of land degradation in the world (UNEP 2002)

solution over the long term. However, there are also several environmental and yield-related concerns that put emphasis on integrated use of all possible resources in an efficient way (Mäder et al. 2002).

Integrated Soil Fertility Management (ISFM) combines the use of both organic and inorganic sources to increase crop yield, rebuild depleted soils and protect the natural resources (Evans 2009). Organic amendments increase the efficiency of inorganic fertilizers through positive interactions on soil biological, chemical and physical properties. The ISFM optimizes the effectiveness of fertilizer and organic inputs in crop production. This approach can rehabilitate degraded soils and restore their sustainable productivity. Therefore, ISFM is an effective strategy for sustainable agriculture on degraded soils.

Replenishment of soil nutrient pools, on-farm recycling of nutrients, reducing nutrient losses and improving the efficiency of inputs on degraded soils are much more important than on normal soils. In this chapter, we have presented ISFM for eroded, nutrient-depleted and salt-affected soils. Special emphasis is given to degraded drylands. In the end, possible conclusions are drawn for sustainable productivity on degraded lands by ISFM.

50.1.1 Land Degradation Processes and Soil Fertility

Under increased human population pressure, agricultural yields could fall as land becomes more degraded, putting the livelihoods of millions of subsistence farmers at risk. Much of world's cultivated land is being degraded by soil erosion, nutrient depletion, desertification, deforestation, salinization, contamination and overgrazing (Bai et al. 2008). Degraded lands are categorized as less productive. The main reason behind low productivity is reduced soil fertility. There are several human activities that significantly reduce soil fertility. Amongst the major land degradation classes, water and wind erosion are irreversible degradation while salinization and compaction are reversible. Most of the vegetation degradation, also called desertification, is irreversible in the drylands.

Deforestation for farming or timber needs has seriously increased soil erosion and nutrient depletion of fertile lands (Irshad et al. 2008). Accelerated soil erosion and destruction of soil structure including loss of organic matter are other consequences of the same mismanagement. Increased but unbalanced fertilization of crops has led to different environmental and economic concerns. Intensive farming on poorly managed agricultural lands has further depleted soil nutrients because of poor farming practices (Gruhn et al. 2000). Artificial irrigation system has led to salt-affected and waterlogged soils. Soil contamination by industrial waste is another outcome of artificial irrigation. Overgrazing, on the other hand, has also resulted in reduced soil productivity. This is due to loss of soil cover, resulting in loss of soil organic matter and loss of moisture-holding capacity and nutritional status of soils. This can lead to massive erosion especially by water. As soils' productivity decline, farmers move on to clear more forests, where the same cycle begins again (Fig. 50.2).

50.1.2 Eroded Soils and Fertility Management

Soil erosion is a complex process that depends on soil properties, ground slope, vegetation, land use and intensity and amount of rainfall (Montgomery 2007). In most cases, soil erosion is outcome of mankind's unwise activities of overgrazing, deforestation and unsuitable cultivation. These practices leave the land unprotected and vulnerable for erosive rainfall and windstorms (Kelley 1983). Sheet erosion is most common type of erosion that removes soil at roughly the same rate as soil is formed. However, net losses of soil are much faster in accelerated soil erosion due to human intervention. The detachment, transportation and deposition of soil from one place to another place significantly reduce its productivity potential. Use of powerful agricultural implements, in intensive mechanical agriculture, has compacted soils. This is known as tillage erosion.

Soil surface layer has more organic matter and nutrients than subsoil. Soil erosion peels away this surface layer. Consequently, soil continues to be deteriorated and becomes unproductive. The goals of soil fertility management on eroded soils are to provide sufficient nutrients to the crop grown, maintain and improve the soil condition and minimize erosion. Proper ISFM approaches rely on cover crops and organic matter application to strengthen the soil against erosive forces. Most crops grow best in soils with organic matter contents between 2 and 5%. Optimum organic

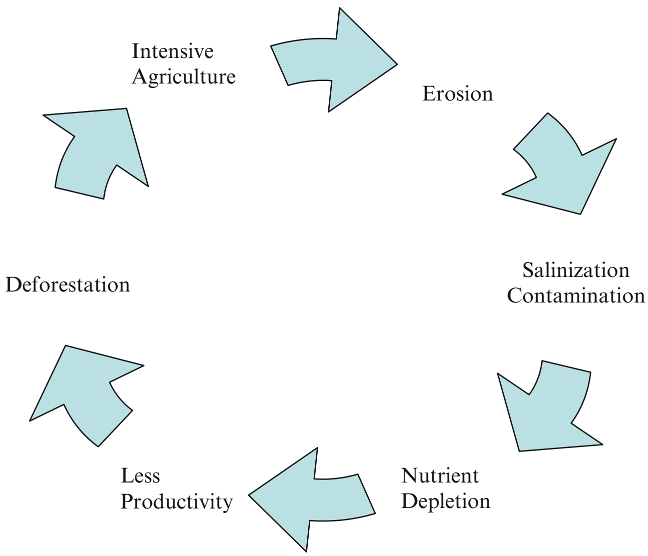

Fig. 50.2 Land degradation from deforestation to deforestation

matter in soils provides several beneficial functions such as minimize soil temperature fluctuations, provides essential nutrients, buffers the soil to changing pH, increases the ability of the soil to hold nutrients and thereby resists soil erosion (Mondini and Sequi 2008).

A combination of available organic and inorganic fertilizers will promote plant growth in these soils. Soil application of P is more effective when applied as enriched composts. Microbial activity and localized acidity in manures and composts can increase the availability of the P. However, total NPK requirements cannot be fulfilled by organic materials alone. Different organic sources and amendments are complementary to mineral fertilizers. Green manuring with legumes adds N to soil, suppresses weeds, scavenges nutrients left in the soil and increases the soil organic matter content. Legumes establish mutualistic relationships with *Rhizobia* that are capable of fixing atmospheric N. Seed inoculation with crop-specific *Rhizobia* strain has proved economical in both soil and food quality long since (Gaur et al. 1980).

50.1.3 Nutrient-Depleted Soils and Fertility Management

Prior to introduction of high-yielding varieties, farmers were using organic sources of nutrients. However, due to inorganic fertilizer application for intensive farming, the use of organic nutrient sources has greatly reduced. Since the introduction of high-yielding and fertilizer-responsive genotypes, use of mineral fertilizers has dramatically increased (Fig. 50.3). Realizing reduced fertilizer-use efficiencies, increased environmental pollution hazards and important benefits of organic

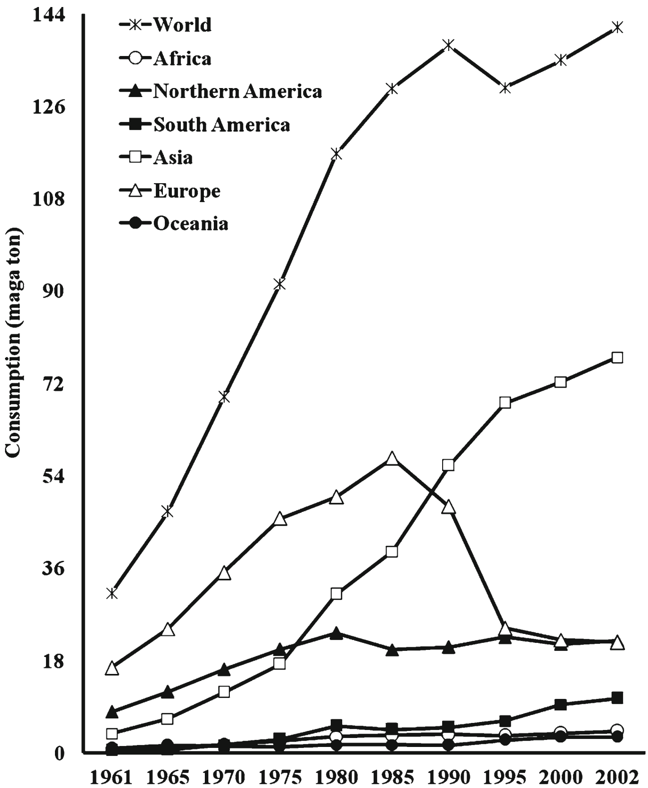

Fig. 50.3 Inorganic fertilizers consumption from green revolution to present (FAO 2010)

amendments, fertilizer use in European countries is decreasing. However, nutrient inputs are generally less than removal. This is particularly true in developing countries where fertilizer application rates are below optimum. Moreover, continuous high yields from intensive agriculture require application of inorganic fertilizers.

Unbalanced application of inorganic fertilizers has deteriorated soil productivity. Moreover, their use efficiency has decreased over time with significant increase in input costs. Sustainable agriculture and ISFM is vital tool for the restoration of soil fertility and productivity. Using plant growth promoting rhizobacteria and their substrates as biofertilizers is also a convincing strategy. For example, seed inoculations with such as atmospheric N-fixing bacteria are viable options for resource-poor farmers of the humid tropics and must be exploited to its fullest potential. For example, the amount of N fixed by legumes can range from 20 to 200 kg ha^{-1} $year^{-1}$ and saves lots of money. Addition of FYM, rice husk and green manures was reported to enhance the plant-available Fe and Mn in soils by 10–15 times. Through an effective ISFM approach, we can produce sustainable yields and can improve fertility status of soils.

50.1.4 Salt-Affected Soils and Fertility Management

Secondary salt accumulation in fertile lands has significantly reduced their productivity potential. This is a problem of arid and semiarid regions where agriculture is dependent on artificial irrigation with poor-quality water. Net precipitation in these areas is less than net evapotranspiration resulting in accumulation of salts on soil surface. Actually, salt problem is one of the major abiotic stresses to the world's agriculture covering 10% of total land surface of the world and about 30% of irrigated soils. On the basis of salinity and sodicity, salt-affected soils are categorized as saline, sodic and saline-sodic soils. Reclamation of severely salt-affected soils is a prerequisite for full yield potential. However, mostly, the conditions are not suitable for reclamation or soils are only marginally salt-affected. Therefore, one has to live with salinity. Efficient, balanced and integrated nutrient management is an integral part of saline agriculture or more comprehensively the *biosaline agriculture*.

Crops in sodic soils invariably suffer from inadequate N supply. High pH and exchangeable Na effects N transformations, thereby affecting the efficiency of applied N. Ammonium is the form of mineral N that accumulates and is subjected to major loss (10–60% of applied fertilizers) through volatilization (Lin et al. 2007). Sodic soils are highly deficient in organic matter and N, and about 25% more N is recommended than normal soil. In general, N efficiency is low in sodic soils due to high losses. Under such situations N-use efficiency can be increased by integrated use of organic and inorganic sources of N. In sodic soils, single superphosphate is a better source of P than other phosphatic fertilizers because it contains appreciable amount of calcium in the form of gypsum ($CaSO_4 \cdot 2H_2O$). Continuous use of fertilizer P, green manuring and FYM to crops significantly enhanced the yields and improved available P status of soils (Singh et al. 2009). Therefore, it is extremely important to integrate the use of organic resources and chemical amendments for sustainable higher production from sodic soils.

Excess soluble salts in the soil solution adversely affect the availability of nutrients to crops. Ionic imbalance and/or nutrient stresses are important limiting factors for crop production. Split application of N as urea should be followed to overcome losses. Both P and K fertilization of crops in saline soils help in alleviating adverse effects of salinity and improving water and N-use efficiency. Saline soils are well supplied with secondary nutrients, and crops do not require further application. In general micronutrient deficiencies have not been widely reported in saline soils. However, Zn is reported deficient in saline soils, and its application helps the crops to alleviate salinity stress. Application of FYM, pressmud, poultry manure and Sesbania green manure mitigates the Zn deficiency to greater extent (Abrol et al. 1998). However, integrated use of Zn and poultry manure is more effective in ameliorating Zn deficiency as compared to Zn sulphate alone, root dipping, Zn sprays and zincated urea (Holb and Nagy 2009). Saline soils under sub-surface drainage may require application of micronutrients. Green manuring in saline soils provides essential nutrients and restores soil physical and chemical properties. Continuous cropping with balanced use of organic and inorganic nutrients will increase yields per hectare.

50.1.5 Degraded Drylands and Fertility Management

Drylands are scattered across about 100 countries covering over 40% of the earth's land surface. People living in drylands of developing countries, about two billion, are amongst the poorest in the world (IUCN 2003). Land degradation in the drylands is an obvious problem. For United Nations Environmental Program (UNEP), desertification refers to a collection of land degradation processes: (1) vegetation degradation, (2) water erosion, (3) wind erosion, (4) salinization, (5) soil compaction and (6) soil fertility decline (UNEP 2002). Therefore, desertification is land deterioration in arid, semiarid and dry subhumid areas resulting from various factors, including climatic variations and human activities (UNCED 1992). Large proportion of dryland areas have low inherent fertility and exhibit a variety of constraints such as nutrient deficiency, low organic matter, moisture stress and high erodibility.

Dryland degradation is widespread in both developing and developed countries. Rangeland degradation is a centuries-old problem in Africa, Asia and the Mediterranean zone of Europe (Dregne 2002). Similarly, dryland salinity is a severe problem in Australia, Canada and the United States (Pannell and Ewing 2006). Wind and water erosion are worse in the semiarid and dry subhumid climatic zones than in the drier regions. Soil compaction, on another hand, undoubtedly reduces crop yields. Improved utilization of the better dryland cropping areas will allow climatically marginal cropland to be returned to good grazing land. Therefore, green drylands are requirement of the time (Lee and Schaaf 2009).

The ISFM balances chemistry, physics and biology in the soils via improved organic carbon content, appropriate mineral balance and a diverse and abundant soil life (Lal 2006). This helps to stabilize the fragile soils. The farming system is intended to enhance biological activity in soil, enabling a balanced supply of required minerals for effective plant growth, providing energy to plants and grazing animals. Active management of the soil food web, remineralization and substantial increase of soil organic carbon are essential to reaching ecologically sustainable production and a sustainable agriculture system. Such a system produces healthy food with good taste and structure (i.e. availability of calcium and silica) and extended shelf life.

50.2 Conclusion

Fertile soils with good physical properties to support plant growth are essential for sustainable agriculture. However, human-induced soil degradation processes has significantly reduced crop productivity of soils. Main reasons of low productivity are poor fertilizer and water management, soil erosion, drylands and salinization. Degraded lands are the sources of food and fibre for a major part of the world. Continuous cropping and inadequate replacement of nutrients removed in harvested materials, lost through erosion, leaching and gaseous emissions have further depleted

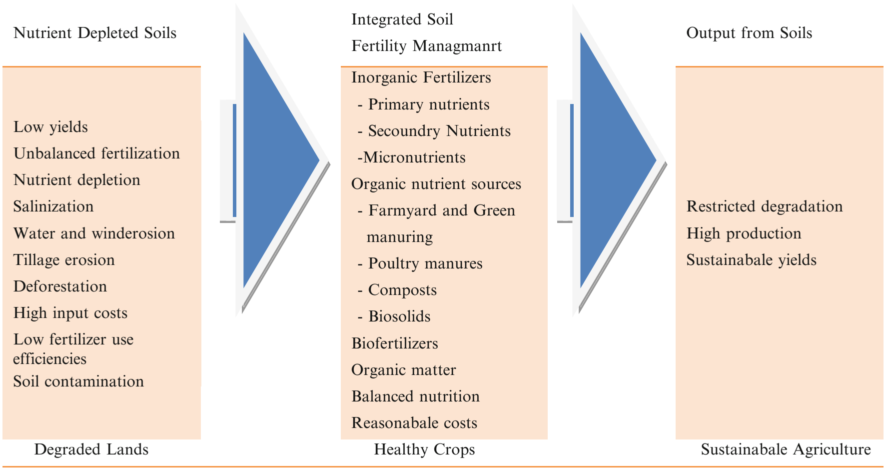

Fig. 50.4 A simplified way towards sustainable agriculture through integrated soil fertility management on degraded lands

fertility. This has led to reduced soil organic matter for optimum plant growth levels. Integrated soil fertility management combines both organic and inorganic materials, used with close attention to timing and placing of the inputs to maximize nutrient-use efficiency on sustainable basis. The road map of ISFM is simple but requires lot of efforts (Fig. 50.4).

The ISFM approach is much more important for degraded lands than for normal soils. However, research in optimum utilization of resources at local level is suggested. The ISFM should base on soil fertility status and valuable local inputs available, thereby increasing the income with high value to cost ratio for sustainable higher yields. Conclusively, ISFM can play a major role in improving farm output from degraded lands and ultimately in sustainable agriculture for the poor farmers.

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