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Improving Soil Health and Soil Security for Food and Nutrition Security in Nepal

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Abstract

Soil health and soil security are intrinsically interconnected with food and nutrition security. Hence, their improvement is necessary for a normal functioning of terrestrial ecosystems, including but not limited to increasing biodiversity and crop productivity and improving people's livelihoods. This chapter reviews the soil fertility status across various agro-ecological or geographic regions of Nepal, soil-related constraints to crop production, factors affecting soil fertility decline, improved soil management practices, soil-related policies and strategies, and contribution of soil to food and nutrition security in the country. Comparisons with south Asian literature are also made wherever relevant. Soils show spatial variability across agro-ecological or geographic regions. Soils across hills and mountains are light-textured, shallow, and susceptible to erosion while low-lying areas including Terai have heavy textured soils with greater depth, and prone to flooding. Majority of the soils in the country are acidic, low in organic carbon and total nitrogen, and deficient in zinc, boron, and molybdenum. Soil fertility is in declining trend mainly due to soil nutrient mining, depletion of soil organic matter, soil erosion in hills and mountains, and inappropriate use of chemical fertilizers in Terai region. Long-term cropping systems experiments conducted across research centers and farmers' fields have indicated that integrated nutrient management with organic inputs and inorganic fertilizers is necessary for maintaining soil nutrient balance and enhancing productivity, profitability, and sustainability of cropping systems. The contribution of soil to food and nutrition security is discussed in relation to the importance of

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improved soil management practices including the use of organic inputs (manures, compost, residues), inorganic fertilizers, legumes in crop rotation, green manures, cover crops, and mulching, in-situ manuring, strip cropping, hedgerow/alley cropping, and practicing reduced or minimum tillage within the framework of integrated plant nutrient management. Improving soil information systems and site-specific nutrient management using digital technologies such as digital soil maps, mobile soil testing labs, and Nutrient Expert-based site-specific nutrient recommendations are also discussed. The chapter also highlights policy implications and recommendations for increasing food security through maintaining soil health and soil security and achieving various SDGs, in particular SDG #2 (end hunger, achieve food security and improve nutrition), #6 (water quality), #13 (climate action), and #15 (life on land) in Nepal.

Keywords

Digital soil map · Fertilizer recommendation · Food security · Nutrient management · Soil management practices

8.1 Introduction

Globally, soils provide food for close to eight billion people today. To achieve global food security for 9–10 billion people by 2050, food production through agriculture must be increased by 70% (ELD 2015). Achieving global food security and reducing hunger is a challenging task, particularly in the context of declining soil fertility due to land and soil degradation. Thus, improving soil fertility can play an important part of the solution (Usman et al. 2018). Healthy soils are pivotal for food security as food production depends on well-functioning soils. This requires better understanding of the properties and processes of soils at national and international scales.

It is estimated that 33% of soils globally and 52% in tropics are moderately or severely affected by soil degradation including erosion, acidification, salinization, contamination, chemical pollution, and compaction (ELD 2015; Hossain et al. 2020). The land degradation could potentially reduce global food productivity by 12% and increasing food prices by 30% over the next 25 years (ELD 2015). Therefore, the quality and fertility of agricultural lands have to be improved to feed the growing population. Sustainable management of soil health and maintenance of soil security are important to achieve several Sustainable Development Goals (SDGs) of the United Nations, in particular SDG 2 (end hunger, achieve food security and improve nutrition), SDG 6 (water quality), SDG 13 (climate action), and SDG 15 (life on land) (Bouman 2020). Soils directly relate to seven of the SDGs (Bouman 2020), with the reminder indirectly related through the contribution of soil ecosystem services (Keesstra et al. 2016).

Soils of south Asia provide food for almost 1.8 billion people, but are prone to degradation due to, but not limited to, increased erosion, soil acidity and alkalinity, drought, and submergence posing a threat to future food security. Nepal, a landlocked country in south Asia, has fragile ecosystems with about 83% of the area occupied by hills and mountains and the remaining by leveled or undulating lands in Terai (plain) and Inner Terai regions (Krupnik et al. 2021). Accordingly, soil fertility status vary across agroecologies, land types, and cropping systems. This paper discusses the importance of soil in achieving food and nutritional security in Nepal including (i) soil security and its relationship with food and nutrition security, (ii) soil fertility status and factors affecting soil fertility decline, and soil and nutrient management practices, and (iii) research and policy implications for augmenting the role of soil in achieving the food and nutrition security. The chapter is based on the review of the published literatures, web-based references, and a long practical experience of the authors in Nepal.

8.2 Soil Security and Its Relationship with Food and Nutrition Security

Soil security is concerned with maintaining and improving soil resources to produce food, fiber, and freshwater, maintaining the biodiversity and ecosystem services and contributing to energy and climate sustainability and human health (McBratney et al. 2014; Gomiero 2016). Addressing soil security through enhanced soil care and best management practices sustainably improves food, fiber, and water quality (Kopittke et al. 2019; Pozza and Field 2020). Soil degradation can have the substantial impact on food security as it reduces crop productivity and nutritional quality of food, and adversely affecting human health (Bindraban et al. 2012; Jones et al. 2013). It is evident that achieving food security is impossible without healthy soils.

Soil security has five dimensions—capability, condition, capital, connectivity, and codification (5Cs) (Pozza and Field 2020; Fig. 8.1). For each dimension there is the common question of how they contribute to the measurement, analysis, and/or management to the six global challenges of food, water, and energy security, maintaining biodiversity and human health, and adapting to or mitigating climate change. Ball et al. (2018) considered three types of connections (direct, indirect, and temporal) within a framework of soil connectivity to facilitate delivery of soil-related messages to three distinct target audiences (Table 8.1). They showed the importance of transferring agriculture by sensible soil management for food security, prevention of soil degradation, and soil restoration. Pozza and Field (2020) mapped the relationship between food and nutrition security and soil security in line with a subset of the SDGs (Fig. 8.1). They described that the natural factors such as climate and environmental systems, and anthropogenic factors such as socioeconomic and political systems affect the interactions between food and nutrition security and soil security. "Condition" aspect of soil security has strong interaction with "availability" and "codification" with both "availability" and "stability" while "capital" has no or weak interaction with "access" and "codification" with "utilization" aspects of food and nutrition security. Bouman (2020) applied 5Cs for the understanding of the relation between soil security with food and nutrition security which can make future soil research much for effective.

8.3 Soil Fertility Status in Nepal

Soil fertility status varies across agro-ecological zones of Nepal (Fig. 8.2). In general, soils across hills and mountains are more fertile, i.e., higher in organic matter, total nitrogen (N), available phosphorus (P), and potassium (K) compared to soils across Terai region. However, soil fertility is in declining trend across the country due to various natural and anthropogenic factors, such as losses of organic matter and nutrients through erosion; low use of organic inputs such as farmyard manure (FYM), compost, green manuring; increasing cropping intensity and residue removal; no or imbalanced application of inorganic fertilizers; low or no use of secondary and micronutrients; and nutrient mining (Tripathi 1997). Soils of hills and mountains are prone to erosion because of steep slopes and geologically active and fragile ecosystems. Soil erosion and runoff are however highly variable due to diverse land use, soil types and slopes, and climatic characteristics. Bajracharya et al. (2007) reported that annual soil loss from agricultural lands in Nepal ranged 0–105 t/ha depending on soil surface conditions and cover, slope, and rainfall characteristics. Using remote sensing data and GIS tool, Dahal (2020) classified soil loss through erosion based on its severity into six categories–low, moderate, high, very high, severe, and very severe—for the Kathmandu district. It is reported that approximately 80% of soils had low to moderate (0–10 t/ha/yr), while 20% had high to severe (>10 to 80 t/ha/yr or more) soil erosion potential.

The content of soil organic matter (SOM) also shows wide variability across agro-ecological regions of Nepal. Its content is lower in the

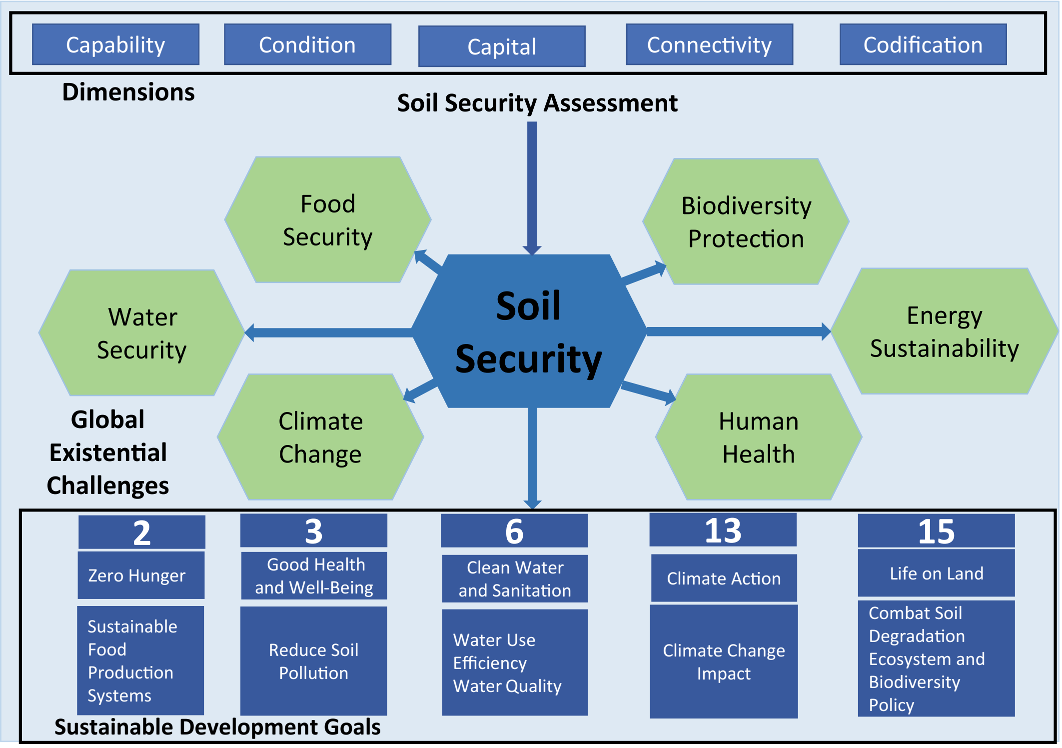

Fig. 8.1 Soil security and the nexus between global existential challenges and sustainable development goals (Adapted from Pozza and Field 2020)

Table 8.1 The framework of three types of connection between soil and people

	Type of connection		
	Direct	Indirect	Temporal
Main examples of creating connection	Hands-on teaching of visual soil evaluation or description	Information on soil and food production	Information on changes to environment due to soil degradation
Message	Good soil quality is important for production	Soil is important for food production, food quality, and human health	Degraded soil can reduce food security and increase environmental degradation
Target group	Farmers, land managers	Public (e.g., gardeners, cooks, school children)	Policy makers, eco groups
Example intended outcome	Improved soil management	Increase in local food production and of environmental awareness	Adoption of a more sustainable farming system

The three types of connections are not mutually exclusive (Adapted from Ball et al. 2018)

majority of Terai soils while medium in the mid-hills (Fig. 8.2). Similarly, there is the substantial effect of altitude on soil nutrients and pH (Table 8.2). Organic carbon (OC), total N, available P and exchangeable K and micronutrients (Zn, Fe, Mn, Cu, and B) are higher at higher altitude compared to that in the lower altitude and Terai regions. Higher nutrients and OC content in hills and mountains could be associated with lower temperature and lower mineralization rates.

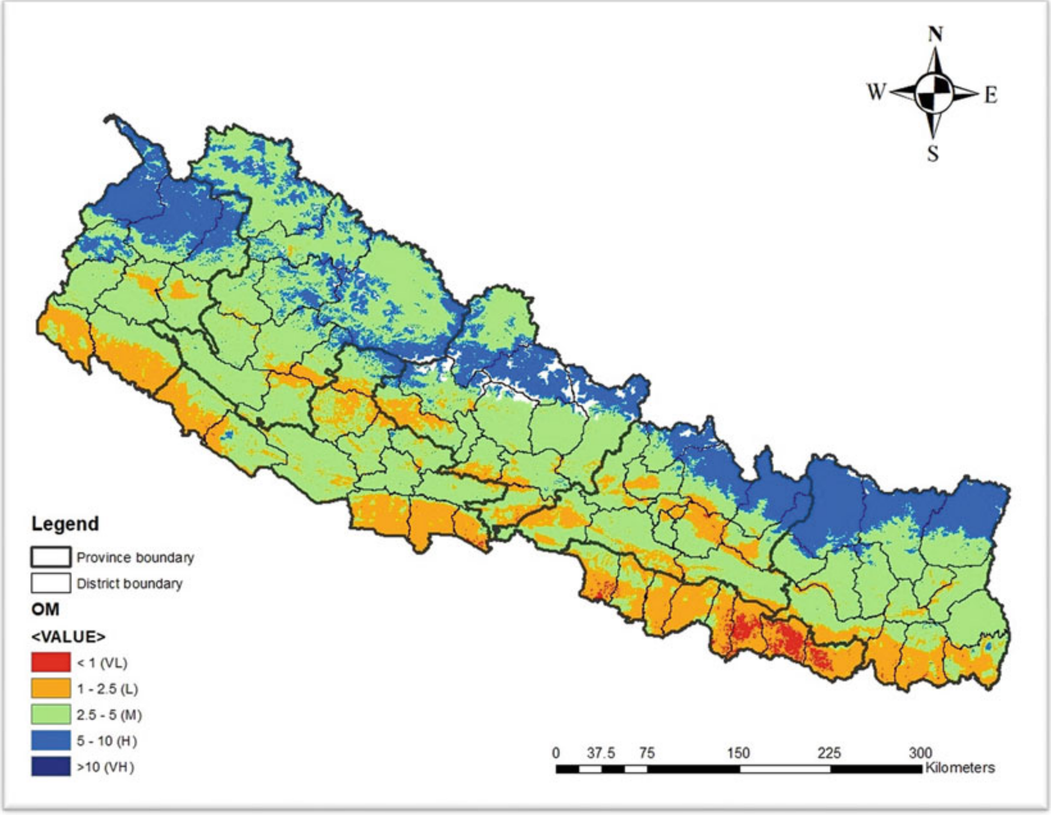

Fig. 8.2 Soil organic matter content across districts in three ecological regions of Nepal (*Source* https://soil.narc.gov.np/)

Table 8.2 Effect of altitude on plant nutrients in the western hills of Nepal (Adapted from Tripathi 1999)

Altitude (m)	pH	OC (%)	Total N (%)	Avail. P (mg/kg)	Exchan. K (cmol/kg)	Avail. Zn (mg/kg)	Avail. Fe (mg/kg)	Avail. Mn (mg/kg)	Avail. Cu (mg/kg)	Avail. B (mg/kg)
<600	6.05	1.07	0.15	30.2	0.40	0.91	174.0	46.3	1.29	0.50
600–1000	5.80	1.59	0.17	43.8	0.32	1.05	179.4	55.9	1.42	0.55
1000–1600	5.64	2.24	0.22	98.1	0.42	0.87	194.6	61.5	1.59	0.65
1600–2200	5.66	2.90	0.27	202.2	0.45	0.85	174.2	68.4	1.68	0.66
Mean	5.79	1.95	0.20	93.6	0.40	0.92	180.6	58.0	1.50	0.59
SE	0.11	0.13	0.01	18.1	0.06	0.16	10.5	10.5	0.29	0.07
P value	0.001	<0.001	<0.001	<0.00	0.10	0.56	0.10	0.30	0.56	<0.05

In addition, soils are shallow in higher altitudes. Hence, together with low soil pH, shallow soils, and soil's proneness to erosion, crop yields are low in higher altitudes. In general, soils across eastern hills and mountains are more acidic than western hills.

Soil physiochemical properties also vary with land-use systems. Ghimire et al. (2018) reported higher total N in forest soils (0.27%) than in agricultural soils (0.07%) (Table 8.3). Available P in all land-use types was low, with the highest amount in *Bari* (upland) soil (24.2 kg/ha)

Table 8.3 Chemical properties of soil (average ± standard deviation) for each land-use type (Adapted from Ghimire et al. 2018)

Land type	pH	OM (%)	TN (%)	AP (kg/ha)	AK (kg/ha)	Textural class
Forest	7.25 ± 0.19	2.56 ± 0.34	0.27 ± 0.07	9.77 ± 0.64	155.0 ± 33.2	SL
Degraded land	5.81 ± 0.37	0.86 ± 0.12	0.07 ± 0.01	1.22 ± 0.03	98.2 ± 12.6	LS
Khet (low land rice)	5.47 ± 0.31	1.40 ± 0.08	0.12 ± 0.04	15.97 ± 2.03	184.7 ± 35.5	SL
Bari (upland sloping terrace)	5.95 ± 0.55	1.56 ± 0.15	0.15 ± 0.03	24.16 ± 3.33	245.6 ± 23.7	SL

OM organic matter, *TN* total nitrogen, *AP* available phosphorus, *AK* available potassium, *SL* sandy loam, *LS* loamy sand

and lowest in degraded soil (1.2 kg/ha). Available K was medium for all land-use types except for the degraded soil.

8.4 Factors Affecting Soil Fertility Decline in Nepal

Depletion of plant nutrients and soil organic matter and increasing soil acidity or alkalinity adversely affect soil fertility and soil quality and reduce crop yields. These ultimately threaten the global food security. Some of the important factors affecting soil fertility decline in Nepal and generally in south Asia are discussed below.

8.4.1 Soil Nutrient Mining

Soil nutrient mining happens when the quantity of nutrients removed by a crop exceeds the quantity that is recycled back and/or replenished in the field. Nutrient mining causes a decline in the native soil fertility and may jeopardize future food security. Soil nutrient mining poses a huge challenge for practicing sustainable agriculture in general and achieving food security in particular (Selim 2020). One of the main reasons for soil nutrient mining is continuous cropping and harvesting (with nutrient removal from soil) without addition of nutrients through organic inputs and fertilizers. Mining can also be associated with other reasons including erosion, imbalanced fertilization, increased nutrient losses through leaching and volatilization, depleting SOM, and inappropriate cultivation practices (Mamathashree et al. 2017). Farmers in mid-hills and Terai of Nepal have been intensively using their land, i.e., growing double or triple crops in a year using high-yielding varieties. In these intensive cropping systems, nutrient removal generally exceeds the amount recycled or replenished resulting in negative nutrient balances.

Rice–wheat (R–W) is an important cropping system in the Indo-Gangetic Plains (IGPs) of south Asia (Timsina and Connor 2001). Long-term experiments (LTEs) and simulation modeling under R–W systems have demonstrated mining of major plant nutrients, leading to nutrient imbalances and deterioration of soil quality (Timsina et al. 1995; Timsina and Connor 2001). Such LTEs, however, confirmed that application of organic amendments can significantly increase soil OC and total N compared to no application (Tiro-Padre et al. 2007). In addition, the application of inorganic fertilizers in combination with organic amendments under R-W system in eastern and western Nepal improved soil fertility and increased crop productivity and economic benefits compared to the application of either one only (Pilbeam et al. 1999). Similarly, in the central Terai (Parwanipur), Gami et al. (2001) reported that both rice and wheat responded to N, but not to P, K, Zn, and S application, indicating that N is the most liming factor but not K and secondary and micronutrients for cereal crop yields. However, with increasing cropping intensity coupled with low or no addition of K and other secondary and micronutrients including S, Zn, B, or Mo

Table 8.4 Effect of chemical fertilizers and FYM on the twenty-year mean grain yield in a long-term experiment on rice–rice–wheat rotation experiment, Bhairahawa, Nepal (Adapted from Regmi et al. 2002a)

First rice (kg/ha)				Second rice (kg/ha)			Wheat (kg/ha)			Yield (t/ha)		
Treatment	N	P_2O5	K_2O	N	P_2O5	K_2O	N	P_2O5	K_2O	First rice	Second rice	Wheat
Control	0	0	0	0	0	0	0	0	0	0.339	1.066	0.532
N	100	0	0	100	0	0	100	0	0	0.719	1.330	0.581
NP	100	13	0	100	13	0	100	18	0	2.577	2.465	1.200
NK	100	0	25	100	0	25	100	0	25	0.630	1.300	0.611
NPK	100	13	25	100	13	25	100	18	25	2.760	3.082	2.301
FYM[a]	80	18	40	80	18	40	80	18	40	2.797	3.138	2.202

[a] FYM applied at the rate of 4 t/ha (dry weight basis) to each crop. Total N, P, and K content in FYM are averaged values

resulting in soil nutrient mining, particularly across the Terai districts. A Terai site in western Nepal (Bhairahawa) has already shown negative K balance, K deficiency, and net K depletion in an R-R-W system, even though recommended levels of fertilizers were added to the system (Regmi et al. 2002a, b; Table 8.4). Thus, application of K fertilizers should be encouraged to improve soil fertility and increase crop productivity (Ojha et al. 2021).

8.4.2 Depletion of Soil Organic Matter (SOM)

SOM plays a critical role in improving soil's physical, chemical, and biological properties. It helps to improve water infiltration and water holding capacity and serves as a slow-release reservoir of nutrients (especially for N, P, and S) and increases microbial activities (Timsina 2018; Maraseni et al. 2008). Declining SOM is a global problem. In Nepal, depleting SOM is associated with increased cropping intensity, low use of organic inputs such as FYM, compost, and crop residues. Also, burning of rice and wheat residues and use of animal dung as fuel, particularly in the Terai region of Nepal, have contributed to decline in SOM. Prior to the introduction of chemical fertilizer in 1952, organic amendments, particularly manures were the major sources of nutrients in Nepalese agriculture (Pandey and Joshy 2000). Most farming across mid- and high mountains still use organic inputs for maintaining soil fertility and increasing crop productivity (Acharya et al. 2007). The magnitude of organic inputs used however varies across agro-ecologies, farm size, and cropping systems. A study conducted in Banke district in Western Terai has shown that small and medium-sized farmers use relatively higher amounts of organic inputs compared to large farmers (Baral et al. 2019). However, evidence indicates that the use of organic inputs is in declining trend in Nepal (Bajracharya et al. 2007). As crop residues are extensively used for animal feed, and little or no residues are returned to the soil (Khadka et al. 2019), it is one of the greatest challenges for improving soil fertility.

Hill farming systems of Nepal have traditionally strong links between three main components of agroforestry systems: forest, livestock, and crop. In this system, livestock gets feed from the forest, and manure from livestock is used for crop production. The hill farmers use tree cuttings and forage from forests and grasses from terrace bunds for cattle feed and for mixing with livestock manure and urine to prepare compost. Therefore, the forest is an important source of nutrient flow to cultivated land (Maraseni and Pandey 2014; Pilbeam et al. 2000). In recent decades, the agricultural labors and livestock number per household in both hills and Terai have reduced substantially because of schooling of children, labor outmigration, and younger generation being less attracted to agriculture (Tripathi and Ellis-Jones 2005; Acharya et al. 2007). Such social changes have been attributed to the reduction in the amount of manure produced and net organic inputs addition to the soil (Subedi et al. 2015).

8.4.3 Imbalanced Application of Fertilizers

Application of inorganic fertilizers is increasing globally as they have higher nutrient contents, are easy in handling, and are less labor-intensive for transportation and application in fields as compared to organic amendments (Timsina 2018). More importantly, increased cropping intensity and introduction of high-yielding crop varieties demand for more nutrients (Timsina and Connor 2001; Timsina 2018). Smallholder farmers in Nepal and in all other south Asian countries use inorganic fertilizers without taking into consideration of right sources, right rates, and right application timing (Timsina et al. 2021, 2022). Majority of the farmers in Nepal have low technical know-how and apply excessive or imbalanced amounts of fertilizers without soil tests or without considering crop nutrient demand (Subedi et al. 2015; Krupnik et al. 2021; Timsina et al. 2021, 2022). These authors reported that the continuous and imbalanced application of inorganic fertilizers can result in soil degradation such as reduced SOM, increase soil hardness, acidification, micronutrient deficiencies, deterioration of soil and water qualities, and loss of agro-biodiversity. Amgain and Timsina (2004) and Timsina et al. (2021, 2022) concluded that cereal yields in farmers' fields are decreased due to decrease in soil fertility, negative nutrient balances, and imbalanced or sub-optimal use of fertilizers. As a thumb rule, nutrients removed by crops at harvest should be replaced into the soil either through organic inputs or inorganic fertilizers. However, Nepalese farmers apply a higher amount of N fertilizer compared to K or other secondary nutrients and most farmers don't apply micronutrients as there is no government recommendation for micronutrients for most crops. Higher use of N is associated with its cheaper price and quick plant response. Andersen (2007) reviewed micronutrient problems in the cultivated soil of Nepal and reported that out of eight micronutrients (B, Zn, Fe, Cu, Cl, Mo, Ni, Mn), B and Zn are the most limited in the Nepalese soils followed by Mo, which limit agriculture production and directly or indirectly affects human nutrition. Therefore, future studies should focus on recommending balanced plant nutrition across different soil types and cropping systems and raising farmers' awareness to adopt balanced fertilization including micronutrients.

8.4.4 Environmental Factors

Environmental factors such as rainfall and temperature determine soil fertility and the supply of plant nutrients. In high rainfall areas, such as eastern hills and mountains, basic cations such as Ca, Mg, and K can be lost by leaching and hence soils are more acidic compared to soils of western hills where average annual rainfall is low. Similarly, soils of hills and mountains where temperature is low have higher SOM and total N due to slow decomposition and mineralization rates compared to warm and tropical Terai regions. In addition, soil parent materials also determine soil fertility. For example, pedologically most of the sandy soils across the hills and mountains are derived from phyllite and schist or sandstones, quartzite, and granite leading to infertile soils (Carson 1992).

8.5 Soil and Nutrient Management Practices

Countries across the world have been adopting different soil and nutrient management practices including different combinations of organic inputs and inorganic fertilizers to improve soil fertility and crop productivity. The ratio of organic inputs and inorganic fertilizers depends on their availability and objectives of the farming. In this section, we review the existing practices followed by farmers and prioritized practices promoted by the government and non-governmental organizations and then suggest some sustainable soil management strategies for Nepal. These practices are grouped into three categories: nutrient management, soil management, and integrated plant nutrient management practices.

8.5.1 Nutrient Management Practices

Farmers have been applying different organic inputs available on their farms and inorganic fertilizers to fulfill plant nutrient demands. In general, farming across hills and mountains is organic-based where inorganic fertilizers are used as a supplement, while farming across the Terai region is based on inorganic fertilizers and organic inputs used as a supplement. In Nepal, the main approach of nutrient management is the integrated use of organic inputs and inorganic fertilizers (see Sect. 5.3 for detail). Previous studies on inorganic fertilizers are limited to determine optimum rate of major nutrients (NPK) and less importance is given to secondary and micronutrients, use of enhanced-efficiency fertilizers, and improved application methods.

8.5.1.1 Application of Organic Inputs and Incorporation of Rice and Wheat Straw

Increase in SOM content is necessary for sustainable improvement of soil fertility and crop productivity. Commonly used organic inputs, particularly by smallholder farmers in Asia are FYM, compost, and poultry manure. Although these inputs have low nutrient content, they can improve soil's physical, chemical, and biological properties such as increasing water infiltration and water holding capacity and increasing nutrient holding capacity through increased cation exchange capacity, soil buffering capacity, and microbial activity and biomass (Buresh and Dobermann 2009; Timsina 2018). In general, management practices that increase SOM can substantially increase crop yields (Lal 2006; Mekonnen and Hoekatra 2011). In addition to application of organic inputs, organic matter in soils can also be increased by adopting crop rotations, crop diversification, mulching, and maintaining soil cover in the cultivated lands (Kharal et al. 2018).

8.5.1.2 Increased and Balanced Application of Inorganic Fertilizers

Inorganic fertilizers play a critical role to achieve global food security. Fertilizers can increase crop yield by at least 30–50% (Stewart et al. 2005; Roberts 2009). The use of inorganic fertilizers in Nepal has been increasing over the years with the growing popularity of modern agriculture (Shrestha 2010; Takeshima et al. 2016). Their use has grown steadily in the past two decades in the Terai region, while it has stagnated in the hills and mountainous regions (MoAD 2018; Devkota et al. 2018, 2019; CSISA 2019; Krupnik et al. 2021). However, average (national) fertilizer application rates are very low ($N:P_2O_5:K_2O$ is 41:18:18 kg/ha) compared to other south Asian countries (Takeshima et al. 2016). The lower use of inorganic fertilizers is mainly due to its unavailability at the time of application, lack of cash for purchase by resource-poor farmers, frequent changes in government policy on subsidies, and difficulties in transporting to hills and mountains (Subedi et al. 2015). Despite the government recommendations on rates and timing of fertilizer application, Nepalese farmers do not use recommended rates, particularly in hills and mountains due to inaccessibility or timely unavailability due to remoteness and non-affordability due to high prices. Also, the fertilizer recommended rates are old, outdated, and blanket type. They need to be recommended by adopting 4Rs (right source, right rate, right time, and right place) of nutrient stewardship approach to increase their use efficiency and crop productivity. To achieve this, farmers' technical skills on 4Rs need to be improved which could help ensure balanced fertilization and increase fertilizer-use efficiency. Also, the magnitude of fertilizer uses in Nepal, particularly in cereals, needs to be increased to increase productivity and achieve food security target set by the government, but should be used efficiently and effectively (Timsina 2018).

Low fertilizer-use efficiency due to increased losses through various processes is the major problem for increasing crop yields and farm profits and reducing the adverse effects of fertilizers on agricultural and aquatic ecosystems. Losses are more from N fertilizers. Past studies have focused on finding alternative strategies to increase N-use efficiency. Some commonly used strategies are the application of various types of decision support systems (DSS) tools including green seeker optical sensor, soil–plant analysis development (SPAD) meter, and leaf color chart (LCC). Similarly, the use of different enhanced-efficiency fertilizers such as slow-and controlled-release urea, improved application methods such as deep placement of urea, localized placement of boron-, sulfur- or zinc-coated urea, and blended fertilizers are in practice globally for increasing N-recovery efficiency and fertilizer-use efficiency. Few studies conducted in Nepal showed that DSS tools such as green seeker optical sensor and LCC can be alternatives to current practices to improve N-use efficiency of lowland rice (Marahatta et al. 2017; Baral et al. 2021). Baral et al. (2021) found a significant increase in grain yield with urea deep placement over conventional fertilizer application in rice, and N application using green seeker saved significant amount of N and increased N-use efficiency. Similarly, Dhakal et al. (2020) reported 25% N saving with the deep placement of urea briquettes on hybrid maize (Khumal Hybrid-2) in Western Nepal compared to the recommended fertilizer practice.

8.5.1.3 In-Situ Manuring

In-situ manuring is the practice of fertilizing the field by keeping and rearing the animals in the field itself. Generally, cattle and buffalo are kept in the open terraces in hills and mountains of Nepal for a week or so and transferred to other terraces. Such system is continued in winter for 4 to 6 months for making the field fertile. In-situ manuring is also carried out using the migratory flocks of animals (sheep and goats) kept in the transhumance system in Nepal (Aryal et al. 2022). In winter (October/November–April/May), these flocks are brought down from the alpine pasture to feed on crop residues and wild grasses and manure the fields (Subedi et al. 1989). According to Dhital et al. (1990), two nights of in-situ manuring by sheep produced the highest maize yield (2.74 t/ha) followed by cattle manure applied equivalent to two nights of manure (2.41 t/ha). In-situ manuring by sheep for three nights produced significantly higher maize grain (5.49 t/ha) and biomass yield (27.66 t/ha) over the direct application of equivalent amount of sheep manure (Sthapit et al. 1988).

8.5.1.4 Management of Acid Soils

Soil acidity is one of the main factors for declining soil fertility in Nepal (Turton et al. 1996; Khadka et al. 2019). Soils vary in acidity across the agro-ecological regions, with approximately 50% being acidic and needing amendments with appropriate measures to improve soil fertility and crop productivity (Tripathi 1999). Acid soils are caused by five main factors: presence of acid-forming parent materials, leaching of Ca and Mg, continuous use of acid-forming urea fertilizer, removal of Ca and Mg by crop uptake or by leaching, and plantation of pine trees and use of tree litters in degraded hill slopes.

Nepalese farmers correct soil acidity by adopting different strategies including appropriate use of organic inputs and lime ($CaCO_3$). Tripathi (2001) reported a positive response of agricultural lime, FYM, and P fertilizers for maize, wheat, upland rice, and soybean in the acidic soils of eastern, western and central Nepal. Previous studies have suggested that the applications of lime at 2–3 t/ha, manure at 10 t/ha, and P_2O_5 at 60 kg/ha could be the practical solutions for maintaining soil fertility of the acidic soils (Tripathi 1999, 2001). The author also reported that only 40–45% of applied lime was utilized by the first crop with the remaining 55–60% by the succeeding crops. These results suggest that lime should be applied at every 3 to 4 years intervals. Correcting soil acidity with the application of lime could also increase N fixation by legume crops. Schreier et al. (1995) reported significant improvement in biomass production of N-fixing trees and native grasses with the use of agricultural lime and manure in highly degraded acid soil of Jhikhu Khola watershed in Kavre district in mid-hills in central Nepal.

8.5.2 Soil Management Practices

Improvement of soil fertility and soil health is important for improving crop productivity. It requires healthy soils to supply indigenous nutrients or release of nutrients added through organic inputs or inorganic fertilizers. Therefore, it is important to improve soil health by adopting sustainable soil management practices. Nepalese farmers have been using different soil management practices for a long time. Some of the most important practices are discussed below.

8.5.2.1 Legumes in Crop Rotation

Grain legumes can fix a significant amount of atmospheric N, which not only meets its own N demand but also supplies N to soils thereby increasing soil fertility and productivity of the succeeding crops. Plant roots and stubble contain a substantial amount of N which can be utilized by the succeeding crops. After the grain or pods of pulse crops are harvested, the straw can be incorporated into the soil, which not only provides nutrients but also improves the soil's physical and biological properties. In Nepal, traditionally legumes are integrated into crop rotations in many ways such as intercropping, mixed cropping, etc. Inclusion of mungbean after harvesting wheat and before planting rice has shown enormous beneficial effects. In-situ growth of mungbean and incorporation of its residues (after picking of the pods) before rice transplanting supplied 60–85 kg N/ha to rice in Punjab, India (Rekhi and Meelu 1983; Antil et al. 1989). In another study, mungbean N benefit to maize in the summer mungbean-maize was about 40 kg N/ha also in India (Ali and Mishra 2000).

8.5.2.2 Bio-Fertilizer Use

Bio-fertilizers are substances produced through biological processes with significant nutrient value that can be used as an effective source of nutrients. These contain living organisms that when applied to soil, seed, or plant surfaces colonize in the rhizosphere or the interior of the plant and promote growth by increasing the availability of nutrients to the host plant (Brevik 2012). The micro-organisms in bio-fertilizers restore the natural nutrient cycle and build SOM. There are several sources of bio-fertilizers including bacteria, fungi, and algae. Common sources of bio-fertilizers in Nepal's cereal-based cropping systems include *Rhizobium* spp. and *Azolla* associated with blue-green algae (*Anabaena azollae*) primarily in rice fields (Subedi et al. 2015). *Azolla* is a free-floating water fern commonly found in south Asia. When associated with blue-green algae, *Azolla* spp. can fix around 40–60 kg N/ha from atmospheric N. Under optimal conditions, soil incorporated *Azolla* spp. can release as high as 70% of fixed N to rice, providing a slow-release N source in lowland rice fields (Kannaiyan 1982).

Free-living N-fixing bacteria such as *Azotobacter, Azispirillum, and clostridium* spp. also fix N in the non-legume crops such as rice, wheat, barley, millet, and cotton. These are not as common as *Rhizobium* but they have a potential for N fixing in non-legume crops. In recent years, some private suppliers in Nepal are supplying different forms of micro-organisms in liquid formulations such as Effective Micro-organisms (EM), Jeevatu, Jibamrit, etc. and farmers are using them on a limited scale. However, there is no effective quality control mechanism of such liquid micro-organisms, which come from India and are formulated in Nepal.

8.5.2.3 Green Manuring

Green manuring (GM) is practice of growing range of species, particularly legumes together or in sequence with crops and incorporating the biomass in soil during vegetative to flowering stages (Timsina 2018). With the similar efficiency like that of inorganic fertilizers, GM crops release nutrients during decomposition and can improve soil quality and fertility (Becker et al. 1995b; Selvi and Kalpana 2009) by improving soil's physical, chemical, and biological properties, stabilize the soil structure, increase the soil water holding capacity, and enhance soil microbiological diversity (Kumar et al. 2014; Bista and Dahal 2018). Green manures, especially the deep-rooted ones, can absorb the nutrients from deep in the profile and make them available to plants after decomposition. The practice of in-situ manuring of *Sesbania* before transplanting rice is increasing in irrigated rice lands in the Terai region of Nepal, which can potentially substitute about 50% fertilizer N to rice crop (Personal communication with Rice Scientist late Bhola Man Singh Basnet, April 2021).

8.5.2.4 Cover Crops and Mulching

Cover crops are grown *in-situ* in the field while mulches (e.g., leaf, straw, dead leaves, and compost) are either *in-situ* or brought from outside and applied in the field. There are mainly three mulching systems in Nepal: In-situ mulching (plant residues left on the soil after harvest), cut/collect and carry mulching (dried or green plant residues brought from elsewhere and used as mulch), and plastic mulching. Plastic mulches are now getting popular in the mid-hills, particularly in commercial vegetables and fruit orchards. The purpose of growing cover crops or mulching is same: to cover the soil surface and protect soil against wind, reduce soil and water erosion, trap nutrients that may be lost by leaching and build and improve soil fertility, suppress weeds, control diseases, and pests, conserve soil moisture, and promote biodiversity (Van Derwerken and Welcox 1988). Atreya et al. (2008) reported that rice straw mulch is effective in conserving soil and nutrients in mid-hills of Nepal. Best adapted grass or some cultivars of legumes can also be grown as cover crops to improve soil health and protect soil from erosion, provide forage for livestock, or develop wildlife habitats (King et al. 2019). Keatinge et al. (1999) used models to determine the feasibility of six legume cover crops to reach maturity prior to the sowing of the different monsoon season crops in Nepal. Model outputs indicated substantial variability in legume maturity date due to genotype, site, elevation, and sowing date effects. They concluded that cover crops could potentially be grown in autumn prior to sowing of the monsoon crops across most of the mid-hills. Subedi et al. (2015) reported that relay planting of soybeans, cowpeas (*Vigna unguiculata*), velvet beans (*Mucuna pruriens*), and finger-millet (*Eleusine coracana*) into maize crops are traditional practices in the hills of Nepal, which help conserve soil and trap N losses.

Mulches can improve soil properties such as maintaining soil temperature, conserving soil moisture (reduced soil evaporation), improving bulk density, aggregate stability, and nutrient availability, and retarding germination and growth of weeds. Farmers use mulches mainly in ginger, colocasia, sweet potatoes, vegetables, and fruits (Subedi et al. 2015). Mulching can have huge benefits for soil management, especially in the sloping lands in the hills and mountains, which are prone to losses of soil nutrients. Atreya et al. (2008) reported reductions in the annual loss of SOM, total N, available P_2O_5, and exchangeable K_2O by 52%, 46%, 32%, and 53%, respectively by using mulches in a maize-mustard (*Brassica campestris*) cropping system in the mid-hills. The major limitation of using mulches however is the greater labor demand, especially for cut or collect and carry systems.

8.5.2.5 Strip Cropping

Strip cropping is the practice of growing crops in strips or bands arranged against the slope of the land. The crop strips in slope serve as barriers for erosion in sloping lands (Subedi et al. 2015). Acharya et al. (2008) reported that the low-input strip cropping is effective in conserving soil and water through the sieve-barrier effect and could maintain the overall sustainability of the land-use practices in sloping lands of Nepal. They also reported that farm income can be increased by incorporating strips of ginger (*Zingibre officinale*) in maize-based systems in the sloping terraces.

8.5.2.6 Agroforestry Systems

Agroforestry system is practice of growing crops, trees, and livestock together to improve soil fertility, conserve soil and water, and meet food, fiber, and fuelwood requirements. Agroforestry systems are practiced in various forms from time immemorial in hills and Terai of Nepal (Dhakal et al. 2022). Hedgerow intercropping or alley cropping, a form of agroforestry system, is growing mainly leguminous crops or N-fixing plants as hedges between the main crop rows and incorporation of pruned biomass into the soil (Subedi et al. 2015). The benefits of hedgerow system are soil conservation by minimizing erosion, reducing nutrient losses from runoff, addition of SOM and plant nutrients, and nutrients lifting from deep soil into the surface. This system is also known as Sloping Agricultural Land Technology (SALT), or contour hedgerow intercropping system (Subedi et al. 2015). Adoption of this practice in Nepal is however low, mainly because of high labor requirements and the lopped biomass used as fodder for cattle. Chapagain and Gurung (2010) reported that hedgerow systems with Napier (*Pennisetum purpureum*), sun-hemp (*Crotolaria juncea*), and pigeon pea (*Cajanus cajan*) on the terrace edges and risers are proven practices for soil conservation and supplying forages for livestock. Schwab et al. (2015) compared soil quality in three different agroforestry systems: a fully developed agroforestry (AF), a predominant conventional system (CS) characterized by mono-cropping, and a system transiting to AF for two years (TS) in a typical mid-hills region of Nepal. Considering soil pH, SOM, soil total N and Al contents, base-saturation, and electric conductivity, they found higher quality and more fertile soil under AF than under other systems. They concluded that AF systems have the potential to significantly enhance long-term soil quality and productivity as compared to CS or TS.

8.5.2.7 Reduced Tillage

Reduced or no-tillage could be a potential option to reduce soil and nutrient losses (especially from erosion), particularly from the terraced lands and sequester carbon and nutrients in hills and mountains and to increase crop productivity and profitability by increasing nutrient, water, and energy-use efficiencies in the Terai of Nepal (Krupnik et al. 2021; Amgain et al. 2022; Magar et al., 2022a, b). Tiwari et al. (2009) reported that reduced tillage with some residue retention in maize-cowpea system was more effective in maintaining soil fertility and increasing farm income compared to conventional maize-millet system. Similarly, Atreya et al. (2008) reported that reduced tillage can reduce soil erosion and increase soil nutrients, both studies suggesting reduced tillage as a viable option for minimizing soil and nutrient losses without sacrificing crop yields in the mid-hills. Ghimire et al. (2011) reported that soils under an R-W system in Terai sequestered significantly higher amounts of organic carbon in 0–15 cm soil depth under no-tillage as compared to that under conventional tillage.

8.5.3 Integrated Plant Nutrient Management (IPNM) Practices

IPNM is a practice of supplying plant nutrients through the integrated use of organic inputs and inorganic fertilizers together with other soil amendments. Potential sources of organic inputs in Nepalese farming systems are FYM, crop residues, and farm waste, green manures, compost. (Timsina 2018; Selim 2020). Adoption of IPNM improves fertilizer-use efficiency, soil's physicochemical, biological and hydrological properties, and profitability of farming systems. Emphasis on the importance and use of IPNM practices for sustainable agriculture has been given in many studies in south Asia: for example, in India (Bhandari et al. 2002; Yadav et al. 2002; Kabba and Aulakh 2004), Bangladesh (Islam and Sah 1998; Panaullah et al. 2001), Pakistan (Zia et al. 1992; Ahmad and Muhammad 1998), Nepal (Brown and Schreier 2000; Regmi et al. 2002a, b), and Sri Lanka (De et al. 1993). In Nepal, particularly in hills and mountains, farmers adopt IPNM practices, which include the integrated use of FYM/compost, inorganic fertilizers, agricultural lime, crop residues/farm waste recycling, inclusion of green manuring and grain legumes, and catch crops in rotations, and agroforestry practices for improving SOM, protect soil biodiversity, and increase crop yields and income (Vista et al. 2020).

Organic inputs or inorganic fertilizers alone cannot sustain the long-term soil fertility and hence their integrated use is recommended for sustainability of cropping systems (Timsina 2018). Particularly in the shallow soils of mid-hills regions, combined application of organic and inorganic fertilizers is necessary for maintaining soil health and obtaining high yields. Chapagain and Gurung (2010) reported from a three-year study that maize with IPNM practice increased grain yield by 64% and increased yield of the subsequent millet compared to farmer's practice in a maize-millet cropping system. Some past studies have also suggested combined application of organic inputs and inorganic fertilizers for the traditional cropping systems in eastern and western mid-hills and mountains under maize/millet, maize/soybean, and rice-blackgram to increase yields and incomes (Tripathi et al. 1998; Pilbeam et al. 2002).

In addition, integrated use of organic inputs and inorganic fertilizers could help maintain soil biodiversity. Soil microbial communities play essential roles in soil processes such as carbon and nutrient cycling, nutrient uptake by plants, and SOM formation (Kibblewhite et al. 2008; Orgiazzi et al. 2016). Therefore, Mujtar et al. (2019) proposed a holistic approach to soil biodiversity management that strengthens multiple ecosystem functions and provides ecological resilience. Soil biodiversity can have direct and indirect effects on agricultural productivity and food security. Direct impacts occur through plant-soil interactions where specific soil biota impact plant growth and/or plant health, while indirect impacts occur via soil processes in which soil biota are involved, e.g., SOM dynamics, carbon and nutrient cycling, improving soil structure, etc.

We present an integrated nutrient model which should be popularized among the farmers in Nepal but could also be used in other countries of south Asia (Fig. 8.3).

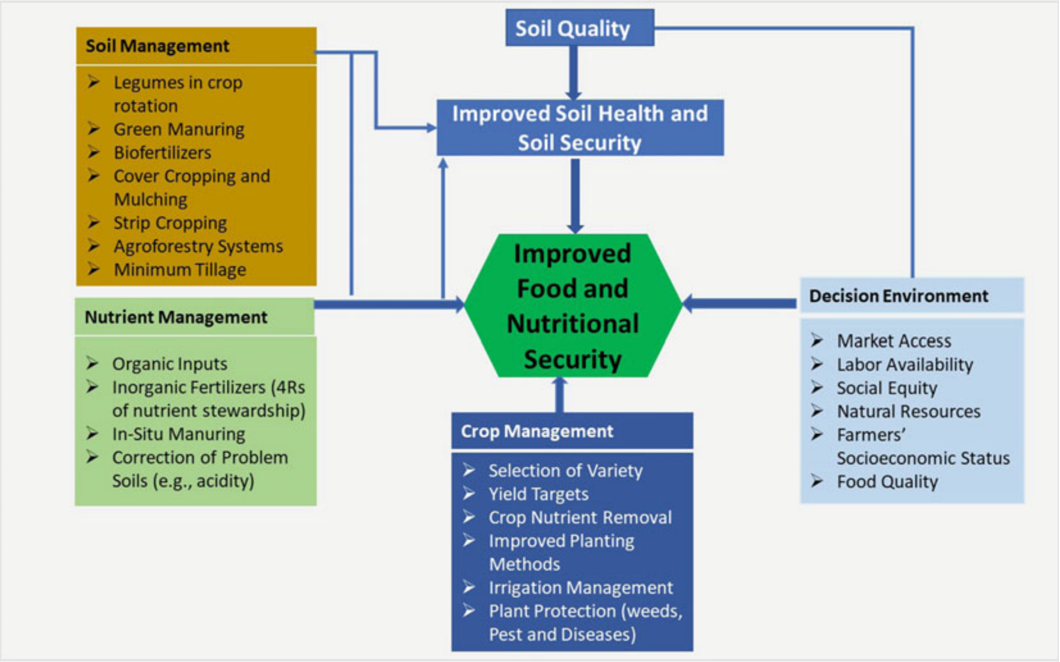

Fig. 8.3 Improving food and nutritional security through improved soil health in Nepal (modified from Sherchan and Karki 2006)

8.6 Improving Soil Information System and Updating Fertilizer Recommendations

In Nepal, access to soil testing facilities is scarce thereby making it difficult for farmers to know the fertility status of their field. On one hand, the country lacks reliable historical data on fertilizer use by crops, seasons, years, and districts. On the other hand, the government fertilizer recommendations are outdated, but yet not been adopted by most farmers. Farmers apply fertilizers based on their own experience rather than following soil-test-based results or government recommendations. This has posed a challenge for farmers and extension workers to determine the right amount of fertilizers for particular crops and sites. The lack of a well-developed soil information system and soil fertility maps makes it difficult for the government and other stakeholders to develop strategies for soil fertility management and fertilizer recommendations for crops. To address this gap, NARC's National Soil Science Research Center in partnership with the "Feed the Future Nepal Seed and Fertilizer project" has recently developed a digital soil map (DSM), which gives output at 250 × 250-m resolution (Hengl et al. 2017). The DSM predicts location-specific soil properties including OM, total N, available P_2O_5, and K_2O, soil acidity, and micronutrients Zn and B across the country. Maps could be used by farmers, policy makers, extension workers, and agro-input retailers as an evidence-based DSS tool to receive location-specific information for making localized management decisions such as for identifying soil problems and applying correct types and rates of fertilizer. (Vista et al. 2021). Prior to the development of the above national-scale DSM, Panday et al. (2018) had also demonstrated the potential use of DSM to determine the spatial distribution of soil chemical properties of the Bara district in central Terai using the geostatistical interpolation.

Soil mapping can aid in decision-making by planners and efficient fertilizer management by farmers. Pandey et al. (2019) mapped the spatial distribution of three different land-use types (agriculture, agroforestry, and grassland) in Dang district in mid-western region, and reported that SOM and total N contents were in medium-range in all land-use types, with highest in grassland, followed by agricultural and agroforestry lands. Soil available P_2O_5 showed a significant variation between agroforestry and grassland while soil K content was highest in grassland and lowest in agricultural land. Boron was low while Zn was very low in all systems. Such maps can assist farmers in identifying the expected nutrient levels in their fields and allow them to make easier and efficient fertilizer management decisions to increase crop productivity and farm income sustainably.

In addition to above, there are few newer studies on the development and use of the DSM in Nepal. Campolo et al. (2021) used high-resolution remote sensing data and DSMs, as a low-cost and scalable alternative to estimate soil and fertilizer effects on irrigated wheat yield. They demonstrated the potential of crop cuts and satellite data and crop simulation and machine learning to examine the influence of soil on wheat yield, guide precision fertilizer management, and adopt site-specific soil management practices. Likewise, Lamichhane et al. (2021) sourced environmental covariates from remote sensing and used digital elevation models and climatic and national databases for predictive mapping of soil. The predicted maps were found to show more detailed soil information in comparison to the original soil map and could be used for research, planning, and management of land resources.

Interactive IT-based DSS tools and mobile technologies can aid in providing rapid fertilizer recommendations, improve soil fertility, and achieve food and nutrition security. One such development is the use of mobile lab van technique to provide soil chemical analysis service and fertilizer recommendations based on the nutrient status of the farmer's fields. Pandey et al. (2018) used the mobile soil testing lab van to provide soil testing in farmer's fields itself in eight districts in the mid-hills and Terai regions of Nepal. The mobile lab van technique can serve as a model to successfully transfer technology for improving soil health and providing fertilizer recommendations.

The other is the Nutrient Expert (NE) DSS to provide site-specific nutrient recommendations for farmers for their specific fields. Nutrient Expert (NE) for rice, wheat, and maize, developed by the International Plant Nutrition Institute together with national collaborators and based on the principles of site-specific nutrient management (SSNM), has been validated and applied in many countries of Asia and Africa. Amgain et al. (2021) used NE-Rice as a nutrient management protocol in several farmers' fields across Terai and mid-hill districts. They found that the nutrient management had a significant effect (p 0.05) on grain yield and gross margins of rice, with the highest gross margins for NE-based recommendation followed by government fertilizer recommendation (GR) and farmer's fertilizer practice (FFP) for several districts in both mid-hills and Terai regions (Table 8.5). The gross margin and benefit–cost ratio were highest for hybrid rice with NE recommendation followed by improved rice with NE, and lowest for improved rice with GR and FFP in the eastern Terai and mid-hills districts. Dahal et al. (2018) used NE-based recommendations and FFP for maize and wheat at two sites (Morang and Jhapa) in Eastern Nepal and found significantly higher productivity and profitability of both crops from the NE-based recommendation in both sites. Therefore, NE for rice, maize, and wheat can be used as an effective and efficient tool for site-specific nutrient or fertilizer recommendations in Nepal and other countries of south Asia.

8.7 Conclusions, Policy Implications, and Recommendations

Healthy soils play a critical role in improving crop productivity and meet food and nutrition security of the growing population. Therefore, priority should be given to maintain soil security through improving soil health. Healthy soils can maintain balance in ecosystem services including maintaining soil biodiversity, reducing atmospheric pollution, and increasing crop productivity. The study shows that the soil fertility in Nepal is in declining trend due to various reasons including but not limited to less use of organic inputs, continuous nutrients removal from soils without proper replacements resulting in nutrient mining, improper and imbalanced use of inorganic fertilizers, increased cropping intensity, soil erosion, and soil acidity, among others. Declining soil fertility has posed several challenges to increase crop productivity and achieve food and nutrition security.

The Government of Nepal has issued several policies to improve agricultural productivity in general and crop productivity in particular through land or soil management. Some policies directly or indirectly related to soil, land, and fertilizer management are National Fertilizer Policy (NFP) (2003), National Agricultural Policy (2004), National Land Use Policy (2012), National Range Land Policy (2012), Agriculture Perspective Plan (APP) (1995), and Agriculture Development Strategy (ADS) (2015) . A twenty-year APP (1995–2015) has identified chemical fertilizer as the engine of agricultural growth and emphasized increased fertilizer use to attain planned agricultural growth. It is apparent from various policies that the Nepal government has given a priority in mitigating land degradation caused by several reasons including inappropriate land use, soil erosion, etc. However, these policies have been generally ineffective in reducing soil erosion, landslides, and floods in relation to set targets (Chalise et al. 2019).

The reasons for ineffectiveness of various policies include i. Implementation of land management-related policies remains weak. As there are no separate laws to address agricultural land degradation, many sectoral laws and program policies provide the legal context relating to sustainable land development through soil conservation, fertility management, and conservation agriculture, ii. Land (Measurement) Act 2019 B. S. and Rules B.S. 2058 consider classification of land in terms of use such as agricultural, commercial, and residential. Implementation of the

Table 8.5 Grain yield and gross margins from rice under farmers' fertilizer practice (FFP), government fertilizer recommendation (GR), and nutrient expert (NE) recommendation across Terai and mid-hills of Nepal from 2015 to 2018 (Adapted from Amgain et al. 2021)

Grain yield (t/ha)										
Treatments	Dang	Rupandehi	Lamjung (1)	Lamjung (2)	Kavre	Chitwan	Morang	Jhapa	Lamjung (3)	Bhairahawa
FFP	4.9	4.6	4.0	4.9	5.2	3.9	4.4	4.3	4.2	6.2
GR	5.8	5.0	4.2	5.5	5.1	4.3	4.8	3.7	4.7	6.3
NE	6.5	5.4	5.1	7.4	5.8	4.7	5.5	5.1	5.8	6.4
% Increase in										
NE over FFP	32.7	17.4	27.5	51.0	11.5	20.5	25.0	18.6	38.1	3.2
LSD (0.05)	1.02	1.65	0.80	0.55	1.05	0.74				0.34
Gross margins (×1000 NRs/ha)[a]										
FFP	63.8	66.7	19.7	10.5	40.4	48.2	12.5	10.3	57.7	16.9
GR	77.6	77.2	27.7	15.1	32.4	57.7	13.1	9.38	71.5	18.7
NE	86.3	99.1	64.3	21.1	64.5	68.9	15.0	12.5	122	20.0
% Increase in										
NE over FFP	35.3	48.6	231	101	59.7	42.9	20.0	21.4	111.4	18.3
LSD (0.05)	11.5	4.78	2.83	2.02	11.48	22.28				1.1

[a] 1 US$ = NRs 115

above Act is often ignored by the government and rather authorizes the private sector to get involved in transforming agricultural lands into towns and built-up areas, iii. Information on soil quality is hardly available for all agro zones. There is no sincere thrust of the government to change the behaviors of people by encouraging them for increasing soil fertility or harness the optimal benefit from raising livestock that can provide sufficient urine and dung to supplement soil nutrients, iv. There are overlapping roles and responsibilities of institutions and lack of coordination among government agencies, v. Government of Nepal has already amended the Land Act 2021 B.S. twice and each amendment has targeted something other than ceiling. Amendments in regulation and devising other sectoral policies has not adequately discussed nor have encouraged sustainable land management, vi. While the soil erosion and fertility-related problems occur in agricultural lands, the Department of Soil and Water Conservation comes under the Ministry of Forestry and Environment which often ignores the Ministry of Agriculture and Livestock Development, and vii. There doesn't seem to be adequate political commitment on addressing soil conservation, fertility, and land management issues. We suggest that the agricultural and land-use policies give priority to soil conservation and management of agricultural lands to produce more food to feed the growing population.

This review has identified several soil and nutrient management-related challenges specific to agro-climatic zones, cropping systems, and management practices suggesting the need for site-specific solutions rather than a blanket approach applicable to the whole country. Most farmers do not know fertility status of their land and farmers' access to soil testing facilities is limited. Fertilizer recommendations for most crops were developed almost four decades ago and most farmers are not aware of even those recommendations. There are no reliable data on fertilizer use by crops, seasons, years, and districts. National research institutes including Nepal Agricultural Research Council (NARC) and Agricultural Universities are conducting research to address those challenges, but their efforts are not sufficient. An immediate priority should be to collect data on fertilizer use by crops, seasons, and districts and update government fertilizer recommendations for various crops. This would help extension workers to advise approximate fertilizer recommendations to farmers. To provide accurate rates, site-specific nutrient management (SSNM) practices need to be adopted. To understand the farmers' fertility status of their land and develop SSNM practices, recently developed digital soil maps could be an effective guide or tool. Similarly, on-farm trials and demonstrations of improved SSNM technologies such as NE for rice and other cereals in multiple locations across Terai and mid-hills districts could help demonstrate its potential to the farmers, researchers, district- and local-level government agricultural extension officials, and teaching faculties of agricultural universities.

For the sustainable improvement of soil fertility and soil health, NARC has developed a model of integrated plant nutrient system which integrates soil and crop management, the use of organic inputs that are available locally at farm with the combination of inorganic fertilizer. Farmer's awareness should be increased in this approach. In addition, problem soils such as acidity should be corrected by application of agricultural lime. Due to remoteness and rugged landscapes of hills and mountains, farmers' access to agricultural lime however remains a challenge. For this, farmers' access to agricultural lime needs to be increased by Agriculture Inputs Company Limited in partnership with Lime Industry and local-level government and private sector organizations. Supportive policy and markets should be developed for effective and efficient distribution, availability, and affordability of agricultural lime by the local government.

To increase soil fertility and adoption of improved agricultural practices, Government should motivate farmers to adopt efficient soil and fertilizer management practices, which can improve SOM and protect soil biodiversity. Outscaling of the improved practices should be done in close coordination with field-based extension workers and staff from different projects and development partners. Yield and economic benefits of any technology should be demonstrated to farmers to increase its adoption. There should be a strong awareness and capacity-building program for technical staff at all levels of the Ministry of Agriculture and Livestock Development to improve understanding and use of improved soil management practices for increasing soil health and soil security and crop productivity and make the country self-sufficient in food production. There is a need to include soil security in policy planning and link it to achieve food and nutrition security and various SDGs, particularly SDG #2 (end hunger, achieve food security and improve nutrition), #6 (water quality), #13 (climate action), and #15 (life on land).

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