Improving soil health for sustainable development of agriculture in Himalaya

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1. Introduction

About 80% of total geographical area of the Indian Himalayan region is under forests and wastelands compared to 12% under cultivation. Per capita availability of land is only about 0.17 ha. Notwithstanding small arable land resource, agriculture remains to be the mainstay of livelihood of local people in the Himalaya endowed with a huge agro-diversity (Anonymous, 1998). Of late, the region is witnessing rapid strides in the transformation of consumption based hill economy to production based one with increasing attention to remunerative crops including off-season vegetables, large cardamom, edible bamboo and aromatic/medicinal plants, organic farming and a host of agri-enterprizes (Sharma and Minhas, 1993; Sharma et al., 1998; NHB, 2003; Sharma, 2004). With increase in the area under large cardamom farming by 135% during 1975-1995 period, the State of Sikkim contributes 53% of global production of this crop (Sharma et al., 2000). Similar expansion of edible bamboo cultivation now contributes net income of over Rs. 5.5 crores in the north-eastern Himalayan region of India (Bhatt and Bujarbaruah, 2004). For sustaining the new ventures and improving the overall agricultural productivity, we have to direct concerted efforts for overcoming different constraints confronting agriculture (Sharma, 2004). The productivity of apple in Himachal Pradesh and Uttarakhand is still 1-2 t /ha/year compared to over 10 t/ha/year in Jammu and Kashmir. The average productivity of 4 t/ha in the Himalayan region is, however, far below the achievable production of 30 t/ha/year (NHB, 2003). Poor soil health is a serious constraint limiting farm production and profitability.

2. Concept and Meaning of Soil health

From agricultural point of view, soil health may be referred to as the ability of the soil to produce crops. It is conditioned by a number of physical, chemical and biological attributes such as soil erosion, water retention and transmission, mechanical impedance, soil temperature, soil aeration, waterlogging, soil salinity, alkalinity, acidity, nutrient status, organic matter content, microbial biomass carbon and potentially mineralizable nitrogen. Persistence of one or more unfavourable soil conditions leads to unsustainability of an agricultural system. Many indicators of soil quality/health have been suggested (Doran and Parkin, 1994; Larson and Pierce, 1994). These indicators could be qualitative, such as the observational features of the soils or plants growing on the soils or quantitative, such as measures of soil physical, chemical and biological attributes. It is worthwhile to employ visual and analytical soil-site suitability criteria and a number of other simple indicators which are easily and clearly understood by farmers and other land managers. Farmers in United States of America ranked soil organic matter content, visible nutritional disorder in crop and risk to erosion as the three most important attributes of soil health and sustainable management (Romig et al., 1995). Parr et al. (1992) have suggested a more generic set of indicators of soil quality/soil health and management options for sustainable agriculture (Figure 1).

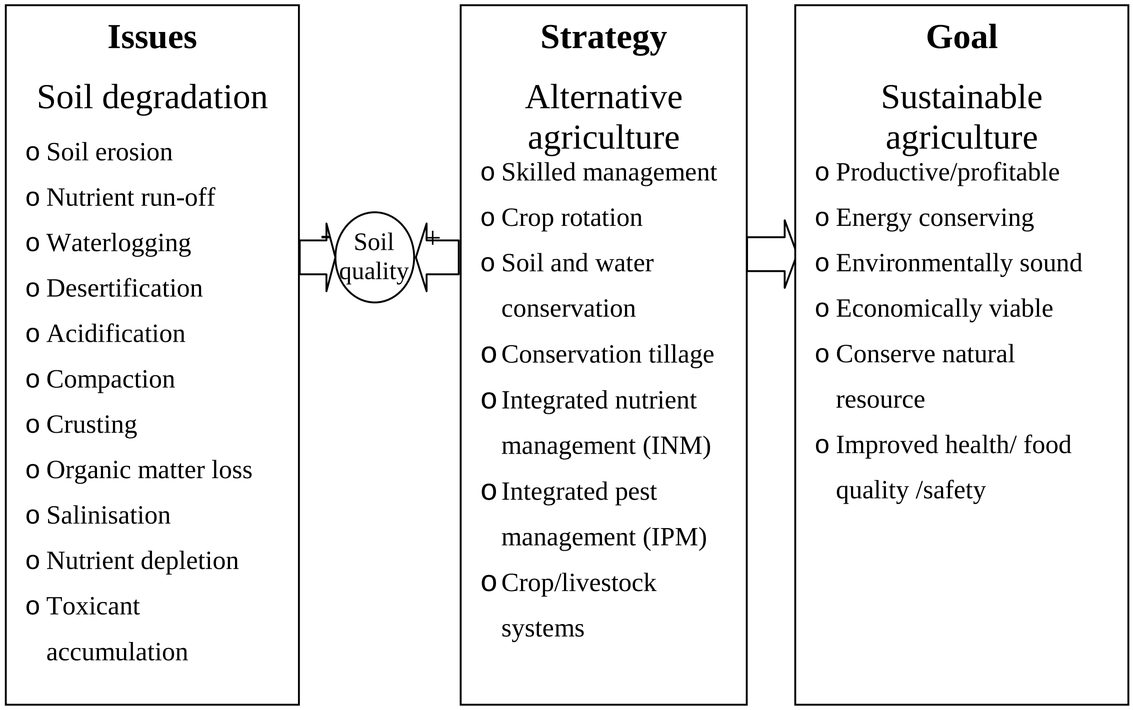

Figure 1. Conceptual relationship of soil quality attributes and management options for sustainable agriculture (Adapted from Parr et al., 1992)

India is facing the problems of stagnation in crop productivity and decline in agricultural growth rate deriving from deterioration of soil health. Restoration of soil health is, therefore, a formidable challenge before us to ensure higher productivity, profitability and national food security. The United Nations Millennium Task Force on hunger has, accordingly, made Soil Health Enhancement as one of the five recommendations for increasing agricultural productivity and achieving food security (Saanchez and Swaminathan, 2005). Therefore, we need to constantly monitor the health of soil resources and devise appropriate management strategies for sustained productivity together with maintenance/improvement of environmental quality.

3. Improving Soil Health

3.1. Arresting soil erosion and degradation

The areas characterized by high intensity rainstorms, sloping lands and highly erodible soils are most vulnerable to soil erosion. Over one-third of the area in Himalayan region suffers from soil erosion and degradation (Table 1), with Mizoram, Himachal Pradesh, Uttarakhand, Nagaland and Tripura showing more severe degradation than the other States. Soil erosion rates are higher than 80 t/ha/year in Siwalik hills and 40 t/ha/year in shifting cultivation areas of the north-east Himalaya (Singh et al., 1997).

The adoption of appropriate soil and water conservation measures is essential for protecting lands from soil erosion and deterioration in soil health. A number of mechanical and cultural management practices like land leveling, contour bunding, contour trenching, bench terracing, contour farming, intercropping, strip cropping, mixed cropping, mulching and vegetative barriers are recommended for checking soil and water loss from the sloping lands. The runoff water could be harvested and stored in suitable storage structures for supplemental irrigations during moisture stress periods. Crop yields may be raised by 100-200 % even with one supplemental irrigation of 5 cm in some regions (Samra and Pratap

Narain, 1998). There are many success stories of enhancing crop yields by improving water management, the watershed projects in Sukhomajri in sub-montane Siwaliks, Palampur in Himachal Himalaya, Fakot in Uttaranchal and in Barapani in Meghalaya being the most widely quoted examples (Samra et al., 2002). Cost effective ways and means of reducing seepage have been worked out to enhance water storage efficiency. Apart from harvesting, storing and recycling run-off, small perennial water sources could also be tapped (Sharda et al., 2006).

Table 1. Soil Degradation (`000 ha) in the Indian Himalayan Region (Provisional)

State	Water erosion	Wind erosion	Physical deterioration	Complex problem	Total degraded area	Total geographical area
Jammu & Kashmir	5460	1360	200	--	7020 (31)*	22224
Himachal Pradesh	2875	--	1303	--	4178 (75)	5567
Uttaranchal	1554	--	2280	--	3834 (72)	5348
Sikkim	235	--	--	--	235 (33)	710
Arunachal Pradesh	4327	--	176	--	4503 (54)	8374
Mizoram	1187	--	--	694	1881 (89)	2108
Manipur	133	--	111	708	952 (42)	2233
Nagaland	390	--	--	605	995 (60)	1658
Tripura	425	--	203	--	628 (60)	1049
Meghalaya	1168	--	146	34	1208 (53)	2243
TOTAL	17754	1360	4279	2041	25434(49)	51514

* Figures in parentheses are percent of total geographical area. Source : NBSS&LUP (2004)

3.2. Adopting integrated plant nutrient supply (IPNS) system

The soils of Himalayan region are, generally, deficient in nutrients like N, P, Ca, Mg, S, Zn, B and Mo. The threshold levels of these nutrients (Table 2) can be supplied by integrated use of inorganic and organic fertilizers. Fertilizer use ($N+P_2O_5+K_2O$) in the Himalayan region (84, 50, 92 and 50 kg/ha in the States of Jammu and Kashmir, Himachal Pradesh, Uttarakhand and Assam, respectively) is far below the national average (104 kg/ha) (Fertilizer Statistics, 2005-06). Apart from lower fertilizer input rates, nutrient composition of added fertilizer does not correspond to that required for optimum crop growth. The inadequate and imbalanced chemical fertilizer use coupled with severe reduction in organic manure input rates has led to multi-nutrient deficiencies in many areas. The deficiencies of micronutrients, particularly of zinc, are becoming more conspicuous in some areas (Singh, 2001). The soils of the cold arid region are low to medium in organic carbon and available P and K and deficient in DTPA-extractable Zn, Mn and Fe (Parmar et al., 1999; Sharma et al., 2006). The continuous use of fertilizers (devoid of sulphur impurities) has made sulphur a deficient and limiting nutrient in Typic Hapludalf soils of Palampur, Himachal Pradesh (Sharma et al., 2005).

Table 2. Threshold deficiency level of nutrients in the Himalayan region

Nutrient	Threshold level
Organic carbon	5 g/kg soil
Nitrogen	280 kg/ha
Phosphorus	10 kg/ha
Potassium	118 kg/ha
Sulphur	22.5 kg/ha
Calcium	1.5 c mol (p^{+}) kg^{-1}
Magnesium	1.0 c mol (p^{+}) kg^{-1}
Iron	4.5 mg/kg
Manganese	1.0
Copper	0.2
Zinc	0.6
Boron	0.1
Molybdenum	0.1

The advent of high yield varieties in India in the mid 1960s called for nutrient management packages, which could sustain intensive cropping systems besides maintaining soil quality on long term basis. In view of this, the Indian Council of Agricultural Research (ICAR) launched All India Coordinated Research Project on "Long Term Fertilizer Experiment (LTFE) to Study Changes in Soil Quality, Crop Productivity and Sustainability" in 1970 at 11 centres representing different agro-climatic regions of the country. These experiments clearly established that application of nitrogen fertilizer alone caused reduction in fertilizer response ratio (kg grain/kg nutrient) from initial 12.5 to 5 over a period of 30 years primarily due to deficiencies of phosphorus and potassium (Figure 2). The response ratio increased with the application of phosphorus along with nitrogen, but its reduction with time was again conspicuous in the absence of application of potassium fertilizer addition. The ratio got stabilized at a higher level only with the balanced application of NPK.

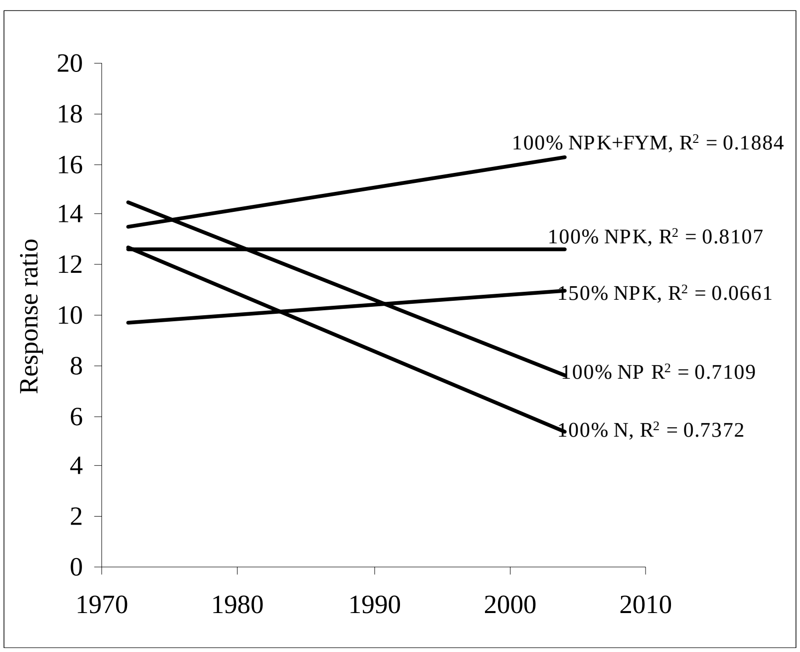

Figure 2. Nutrient response ratios (kg grain/kg nutrient) in cereals(LTFE data over 1972-2003) (Nutrients inputs in kg/ha for rice: N_{90-120}; P_{9-26}; K_{25-50}; wheat: N_{80-150}; P_{26-35}; K_{25-50}; maize: $N_{100-150}$; P_{26-33}; K_{25-82}; subscripts refer to amount of nutrient in kg/ha)

Any further improvement in the response ratio beyond this level could not be effected merely with the addition of higher amounts of chemical fertilizers (as for 150 % NPK). The response ratios showed an upward trend only when chemical fertilizers were supplemented with organic manure (100 % NPK + FYM). The average response ratios of N, NP, NPK and NPK+FYM treatments were 8.1, 10.1, 12.8 and 15.2, respectively (Figure 3). The continued additions of NPK at higher rates without organic manures would induce deficiencies of secondary (Ca, Mg and S) and micronutrients (Fe, Mn, Cu and Zn), thereby, lowering the response ratios (Figures 4, 5, 6, 7).

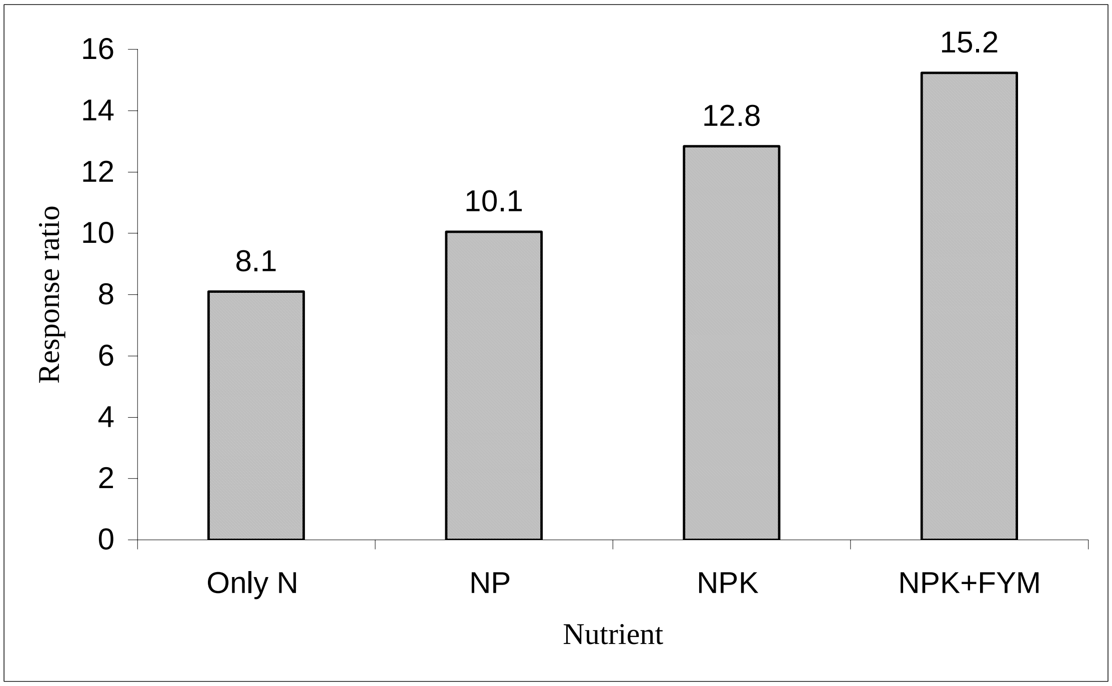

Figure 3. Average response ratios (kg grain/kg nutrient) of nutrients in cereals (LTFE data for the period 1972-2003).

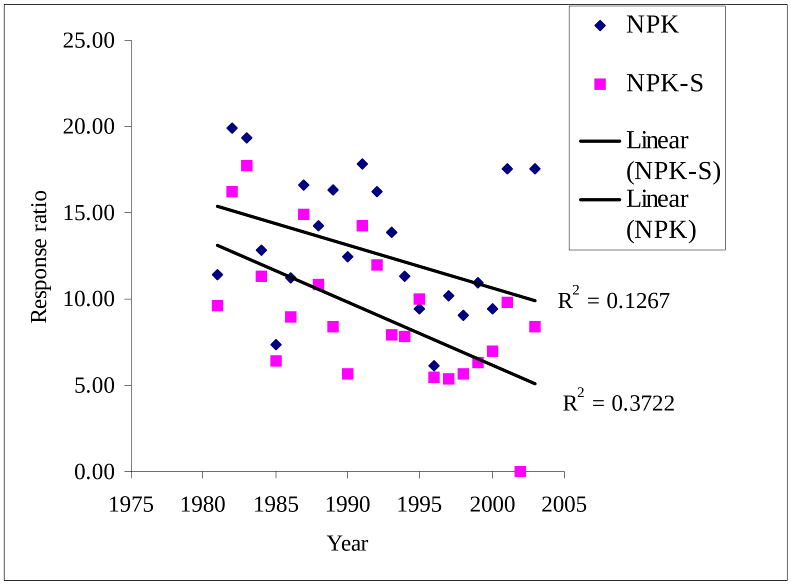

Figure 4. Response ratios (kg grain/kg nutrient) of sulphur in maize at Palampur (based on LTFE data)

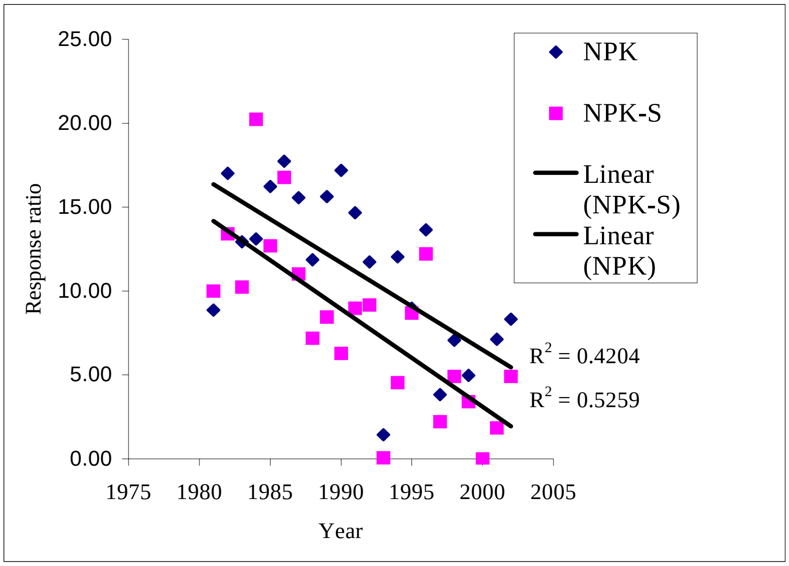

Figure 5. Response ratios (kg grain/kg nutrient) of sulphur in wheat at Palampur (based on LTFE data)

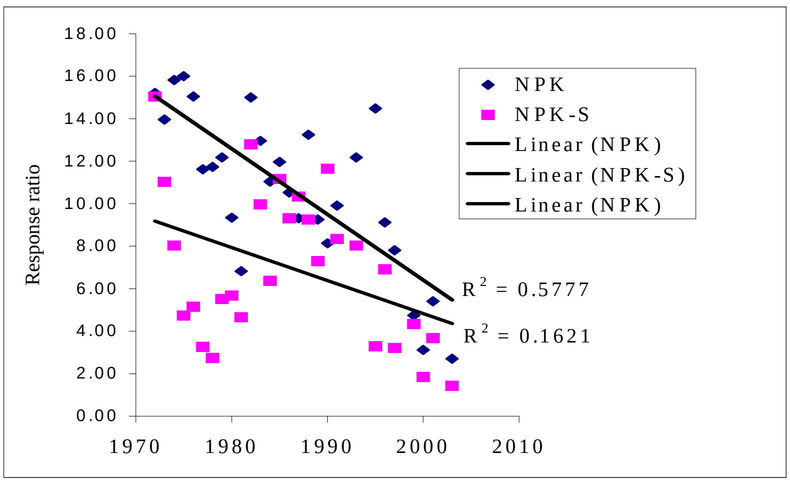

Figure 6. Response ratio (kg grain/kg nutrient) of sulphur in rice at Barrackpore (based on LTFE data)

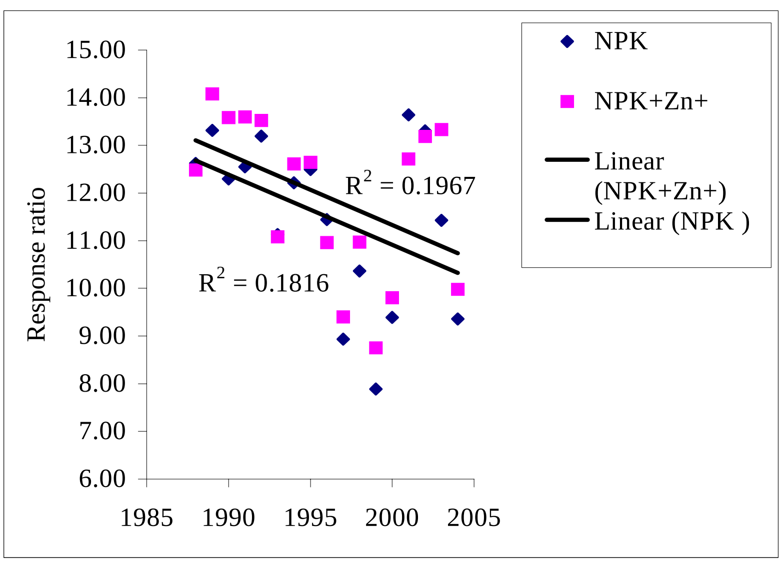

Figure 7. Response ratio (kg grain/kg nutrient) of Zn in cereals (based on LTFE data)

The beneficial effects of balanced and integrated nutrient management on soil health and overall crop productivity have very well been demonstrated by the Long Term Fertilizer Experiments at Palampur, Himachal Pradesh (Sharma et al., 2005). The conjunctive use of chemical fertilizers and organic manure (NPK+FYM) enhanced organic carbon, soil aggregation, water infiltrability, soil available nutrients, microbial biomass-C and microbial population compared to use of chemical fertilizers alone (Table 2). The total productivity of the maize-wheat cropping system under integrated use of inorganic and organic fertilizers was significantly higher over use of inorganic fertilizers alone (Figure 8).

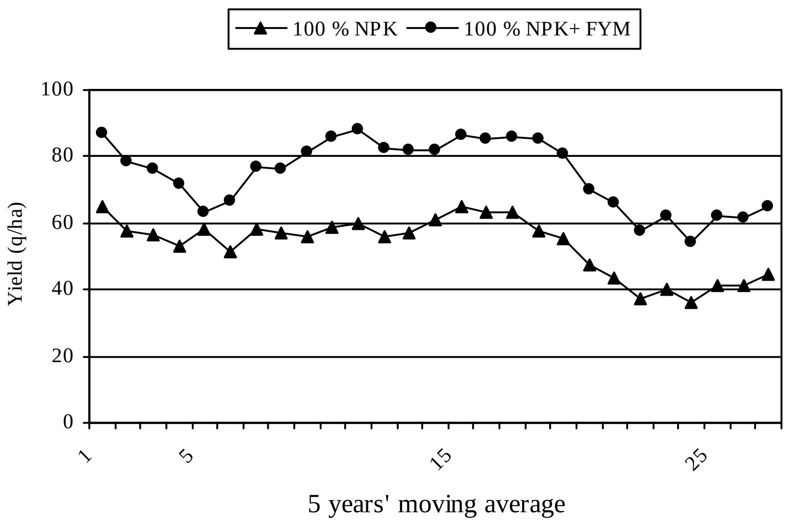

Figure 8. Effect of chemical fertilizers alone and with FYM on total productivity of maize - wheat crop system at Palampur, Himachal Pradesh

Table 2. Effect of chemical fertilizers in the absence or presence of organics on some soil quality attributes

Treatment	Organic carbon (g/kg)	Mean weight diameter (mm)	Infiltration rate (cm/hr)	Available nutrients (kg/ha)			Soil microbial parameter		
				N	P	K	Bacteria (CFUx10^5 per g soil)	Azotobacter (CFUx10^3 per g soil)	Microbial biomass – C (mg/kg)
100 % NPK	9.9	3.14	2.17	282	105	118	11.49	17.5	316
100 % NPK + FYM	13.8	4.02	2.68	293	144	185	28.08	226.16	410

Source: Sharma et al. (2005)

The usefulness of integrated plant nutrient system (IPNS) has also been demonstrated in improving soil health and productivity of important vegetables in cold desert/dry temperate areas (Parmar, 2005). The combined use of major and micronutrient fertilizers, bio-fertilizers and farmyard manure (FYM) helped obtain quite higher yields of green peas, potato and cabbage in Lahaul, Spiti and Kinnaur compared to farmers' practice comprising use of about 8-10 t/ha FYM and and 40% of the recommended level of nitrogen for the respective crops (Table 3). For instance, the yields of pea, potato and cabbage were higher by 36, 42 and 39% respectively, under IPNS over farmers' practice, in Spiti valley. The integrated nutrient management also improved levels of protein, starch, total soluble sugars and vitamins.

Table 3. Yield and economics of off-season vegetable production in cold arid areas of Himachal Pradesh

Crop/Practice	Lahaul		Spiti		Kinnaur	
	Yield (t/ha)	Net returns (Rs.)	Yield (t/ha)	Net returns (Rs.)	Yield (t/ha)	Net returns (Rs.)
Green peas						
Farmer's Practice	9.16	72,052	10.18	70,438	11.35	89,666
IPNS	16.63	1,32,640	15.95	1,03,222	18.22	1,52,182
Potato						
Farmer's Practice	13.99	54,835	12.63	54,199	13.92	57,704
IPNS	18.76	72,091	21.80	1,07,925	20.66	92,527
Cabbage						
Farmer's Practice	17.32	53,690	15.21	51,040	12.38	33,069
IPNS	24.28	72,228	24.38	84,662	20.85	61,111

Farmer's practice = 40% recommended N + FYM @ 8-10 t/ha). Source: Parmar (2005)
Integrated Plant Nutrient System (IPNS) : Fertilizers + Micronutrients + Organic Manure + Bio-fertilizer
Fertilizer inputs (kg/ha):

Pea : $N_{20}P_{26}K_{25}$; Potato: $N_{100}P_{33}K_{46}$; Cabbage: $N_{125}P_{33}K_{50}$

Bio-fertilizer:

- Pea seeds inoculated with Rhizobium, Azotobacter and Phosphorus solubilizing bacteria (PSB)
- Potato seeds and cabbage seedlings inoculated with Azotobacter and Phosphorus solubilizing bacteria (PSB)

Table 4. Extent of Acid Soils in Himalayan region. Source: NBSS&LUP, Nagpur

State	Strongly acidic (pH<4.5)	Moderately acidic (pH 4.5-5.5)	Slightly acidic (pH 5.5-6.5)	Total
Arunachal Pradesh	4.78	1.74	0.27	6.79
Assam	0.02	2.31	2.33	4.66
Himachal Pradesh	-	0.16	1.62	1.78
Jammu &Kashmir	-	0.09	1.48	1.57
Manipur	0.43	1.44	0.32	2.19
Meghalaya	-	1.19	1.05	2.24
Mizoram	-	1.27	0.78	2.05
Nagaland	0.12	1.48	0.05	1,65
Sikkim	0.28	0.32	-	0.60
Tripura	0.06	0.75	0.24	1.05
Uttranchal	-	1.18	2.30	3.48
Total	5.69	11.93	10.44	28.06

The integrated nutrient supply system envisaging conjunctive use of chemical and organic fertilizers is, therefore, the most ideal system of nutrient management. The system enhances nutrient-use efficiency, maintains soil health, enhances yields and reduces cost of cultivation. There is a need of augmenting the supplies of organic manures (farm yard manure, green manure, compost/vermin-compost) and fortified and customized fertilizers supplying secondary and micronutrients to have IPNS on a sound footing. The use of bio-fertilizers is still minimal in hilly regions and requires to be promoted by producing effective strains with enhanced shelf life.

3.3. Ameliorating acid soils

The Himalayan region has large area under acid soils (Table 4). About 17.6 million ha of lands with pH value less than 5.5 are critically degraded with very poor physical, chemical and biological characteristics. The soils suffer due to deficiencies of phosphorus, calcium, magnesium, molybdenum and boron and toxicity due to high aluminum and iron concentration. Chemical fertilizer use is still low in the region. Soil productivity is, therefore, low due to poor soil health. The addition of lime to these soils neutralizes soil acidity and creates favourable environment for microbial activity and availability of nutrients to plants. The conjunctive use of lime and fertilizers, therefore, holds key for higher productivity of these soils. Indian Council of Agricultural Research (ICAR) has evolved a cost-effective technology for amelioration of acid soils (Sharma and Sarkar, 2005). Application of lime @ 2-4 q/ha along with 100 percent recommended doze of NPK fertilizers in furrows at the time of sowing led to a significant increase in yields, particularly of oilseeds and pulses, over farmers' practices (FP) (Figures 9 to 13). While one could reduce acidity by liming, varieties tolerant to soil acidity have also been developed, e.g., Varuna and Sonmukhi of rapeseed, K851 and Sonmugu of summer greengram for Assam and HUR-15 of french bean for Meghalaya.

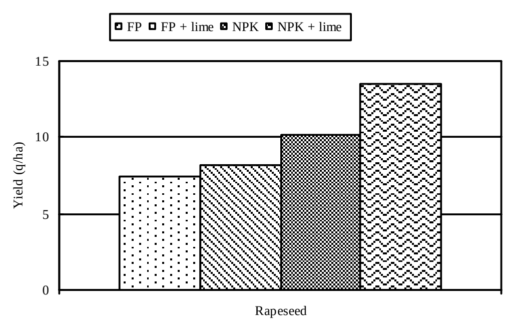

Figure 9. Response of rapeseed to liming and fertilization in acidic soils of Assam

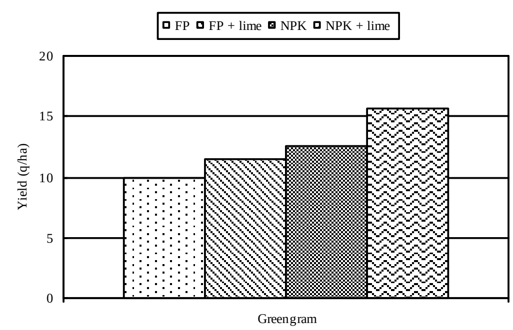

Figure 10. Response of greengram to liming and fertilization in acidic soils of Himachal Pradesh

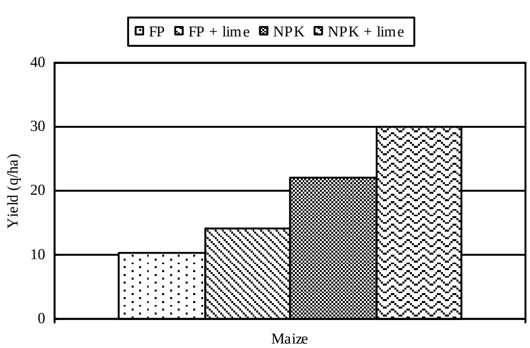

Figure 11. Response of maize to liming in acidic soils of Himachal Pradesh

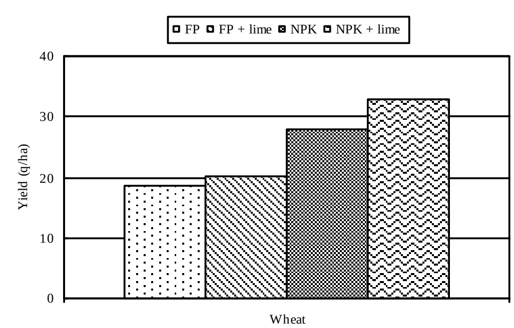

Figure 12. Response of wheat to liming in acidic soils of Himachal Pradesh

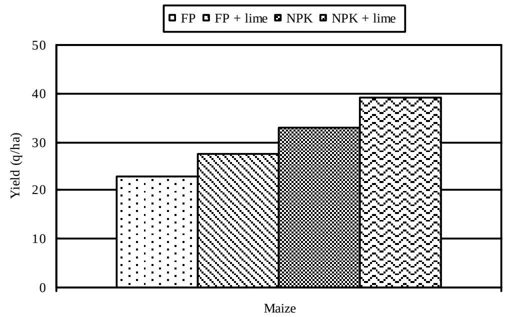

Figure 13. Response of maize to liming in acidic soils of Meghalaya

The cheap and effective liming materials must be made available for the success of acid soil amelioration programme. Although agricultural grade limestone powder and marketable lime are effective, these inputs are not economical and often in short supply.

The by-products of industries like basic slag, lime sludges, phosphogypsum and press mud are rich sources of calcium and serve as cheap liming materials. The Tata Steel Industries, Jamshedpur alone generates about 3 lakh tonnes of basic slag annually. Likewise, paper mills in Assam, Nagaland, West Bengal, Orissa, Madhya Pradesh and Andhra Pradesh produce around 2 lakh tonnes of lime sludge. Besides, there are large deposits of limestone in north–eastern states of Arunachal Pradesh, Manipur, Assam, Meghalaya and Nagaland that could be exploited for producing agricultural grade lime at affordable prices. The materials should meet the specifications of at least 25% calcium oxide and be ground to > 80 mesh size. The Tata Steel Industries is keen to supply basic slag of desired specifications at a nominal price of about Rs. 1000/tonne. The Government should facilitate requisite tie-ups with the industry to regulate marketing and distribution of materials to farmers.

3.4. Strengthening Soil Testing Service

The soil testing has a great significance in making precise fertilizer recommendations to crops. Recognizing the importance, the soil testing was begun in 1956-57 with the establishment of 16 soil testing laboratories in the country. Today, the number has grown to 651, mainly with State Departments of Agriculture and few with the fertilizer companies. The soil testing service is, however, inadequate in having the capacity to analyze only 7 million soil samples/annum against 115 million farm holdings at the country level. A farm holding, therefore, has a fare chance of its being tested only after 15 years or so. Obviously, there is an urgent need to open up more soil testing laboratories in the country including Himalayan region. In north-eastern hill region of India, only 17 out of 77 districts have soil testing laboratories. The laboratories are, generally, ill-equipped, lack facilities for the analyses of secondary and micro-nutrients, manned by inadequate and non-professional staff and have very little state funding. The soil test reports are not delivered in time, making farmers lose their faith in the service.

The soil testing laboratories, therefore, require to be computerized and equipped with the facility for analyses of all nutrients. These need to be manned by soil scientists to ensure precise analyses and proper interpretation of results. The State Agricultural Departments should have a policy intervention in this regard. The states should also come forward for preparation of geo-referenced soil fertility maps at district and block levels to have precise fertilizer recommendations. The National Commission on Farmers has felt a strong need for monitoring of soil health as a sequel to the emerging multi-nutrient deficiencies and deteriorating soil health in many regions under intensive agriculture. Accordingly, the Commission has recommended a countrywide network of 1000 advanced soil testing laboratories. The ICAR is creating facility for soil and plant analysis in 304 Krishi Vigyan Kendras (Agricultural Development Centers) distributed across the country.

4. Conclusion

The Himalayan region, endowed with varied physiography and fine mosaic of micro-climates, offers niches for a variety of cereals, pulses, horticultural plantation and aromatic and medicinal crops. Productivity of majority of crops, however, is low due to a number of production constraints. The impaired soil health due to increased soil erosion, deficiencies and toxicities of nutrients, frequent moisture stress and low soil biological activity is one of the major factors for low productivity. The future gains in productivity in the region can not be realized on a deteriorating natural resource base. There should be regular monitoring of soil health through soil testing and crop yield responses to remove any production constraints. Such a system is still not fully developed for want of institutional, financial and technical support. The Department of Agriculture, Ministry of Agriculture, Government of India has already a central sector scheme with a component of distribution of soil health cards to the farmers in different states. The information on various soil attributes and management needs is to be periodically entered in these cards for maintaining soil health and crop-productivity. The strengthening of soil testing service will go a long way in achieving the desired goals. The district level geo-referenced soil fertility maps need to be prepared speedily for providing back-up to the soil testing service and channelizing customized fertilizers for different areas.

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