An Integrated Nutrient Management System for Sustaining Soil Fertility: Opportunities and Strategy for Soil Fertility Research in the Hills

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1. INTRODUCTION

The soil fertility management systems in the hills of Nepal are dependent upon access to the forest and farm fodder resources, livestock management, crop production systems and the socioeconomic conditions of farmers which includes land tenure, land holding size and external input purchasing capacity.

In the present context, the need to meet a rising demand for food grains due to an increasing population is reflected in increasing crop intensification. In many areas of the country organic sources are no longer adequate to replenish the nutrients removed by crops and trees or lost through other means such as erosion or leaching. Chemical fertilizers are the only easy and ready made materials which can be efficiently used to replenish the deficit, however, their use is restricted in the hills because of transportation difficulties and not being available when needed. Even when they are available the poor purchasing capacity of the farmers limits their effective utilization.

This paper attempts to highlight the soil fertility systems of the hills and present the results of several field experiments carried out by Pakhribas Agricultural Centre (PAC). It also discusses future research strategies.

2. ORGANIC AND INORGANIC SOURCES OF FERTILIZERS

There are three major sources for nutrients in the hills of Nepal. These are: farm yard manure, compost/leaf litters and chemical fertilizers. The contribution from soil microbes, both symbiotic and non symbiotic, in harvesting atmospheric nitrogen is not well documented. However, a number of reports are available that show that symbiotic microbes do improve the productivity of legume crops (Bhattarai, 1987, Gurung, 1993).

In the hills, the use of chemical fertilizers is a relatively new practice among farmers, whereas compost and FYM are age old traditional practices in crop production. It is commonly believed that the production of compost is decreasing; the cause is often related with decreasing forest resources and animal population, but no scientifically documented data is available to verify this statement. The use of chemical fertilizers has increased steadily over the years since their introduction in the early 1960's (Pandey, 1993). The increased use of the major nutrient elements has been calculated at 11.1 percent N per annum, 13.5 percent phosphorus and 8.2 percent of potash (APP, 1994). In the hills and mountain regions, the overall consumption of fertilizers is thought to have grown at 10.5 to 11.8 percent between 1986/87 and 1991/92 (APP, 1994).

Both organic and inorganic sources of nutrients are important for promoting sustainable crop production. Organic sources have many advantages and are considered as complete fertilizers; they also act as soil conditioners. Inorganic sources are mainly seen as a means to meet the high demand for plant nutrients under highly intensified agriculture and to replenish nutrients and correct any imbalances. Reports are available which show that the use of chemical fertilizers in the hills is economically justifiable (Joshi, 1976, Pandey, 1991), but if used inappropriately, there can be adverse effects which result in soil degradation and damage to the environment. Farmers are already reporting adverse effects on soil productivity, stating that to maintain the same yield level increasing amounts of chemical fertilizers have to be used every year. The Agriculture Perspective Planning (1994) gives emphasis to soil fertility research by complementing chemical fertilizers with indigenous techniques and also relies heavily on the use of inorganic fertilizers. Looking at the prospects for Nepalese agricultural development, an integrated nutrient management approach becomes an important issue if sustainable agricultural development is to be achieved.

3. TRADITIONAL SOIL FERTILITY MANAGEMENT SYSTEMS

3.1. Nutrient Flow, Cycle and Balance

A number of the traditional soil fertility management systems and soil classification systems used by farmers in the hills of Nepal have been described by biologists and social scientists (Tamang, 1993, Subedi, 1989, Gurung, 1993). Information on these systems is still relatively sparse. Figure 1 depicts the nutrient flow system and cycle, but quantitative information is lacking. Many of the technical and socioeconomic factors which influence the system are only poorly understood. These external factors, which may have an adverse effect on nutrient cycling, need to be understood by researchers as well as others engaged in development activities.

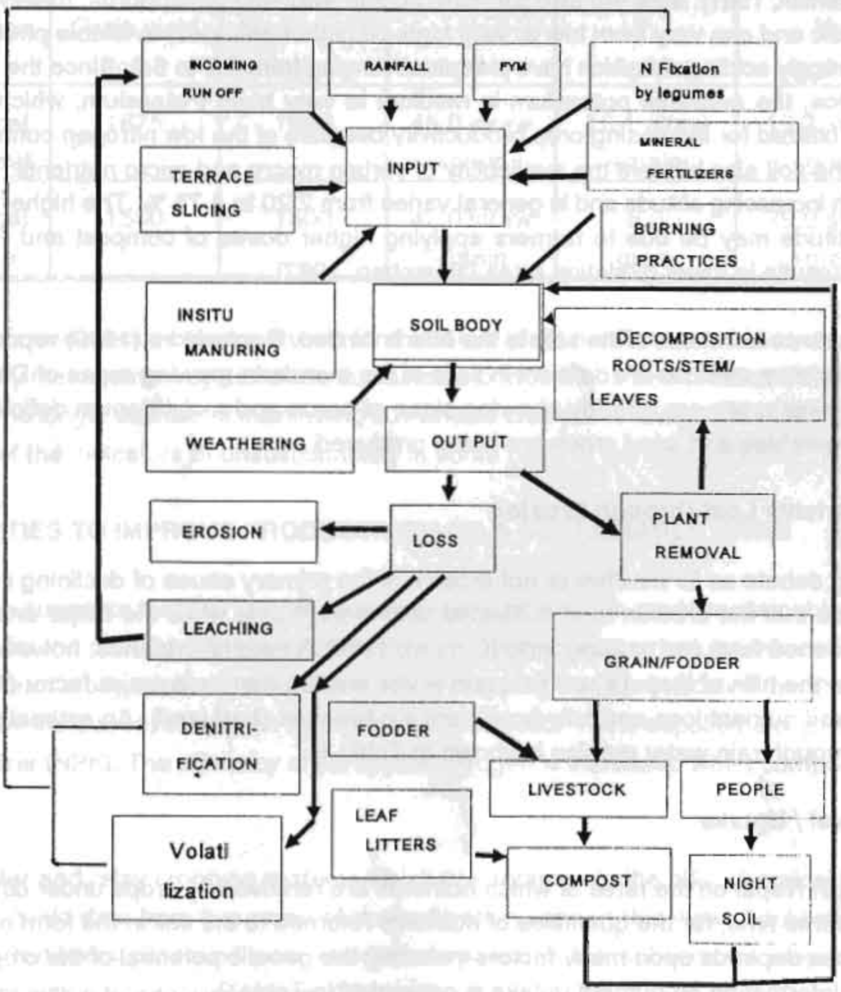


Figure 1. A typical nutrient cycle in a subsistence hill farming system in Nepal.

Soil fertility management as practised by farmers in the hills includes in-situ manuring, use of sediment-laden irrigation water, terrace slicing, burning plant residue, winter fallow and water ponding on khet land. No quantitative estimation of the contribution of these practices to crop production is available. On average, 10 t/ha fresh compost or FYM, with an estimated composition of 0.5% nitrogen, 0.2 % phosphorus and 1.25% potassium on a dry weight basis, is applied to each crop grown in the hills. No information is available as to how much chemical fertilizer is applied to crops and it is difficult to generalize.

Other important parameters to consider when trying to understand the nutrient cycle are the natural ability of the soil to supply and hold nutrients and its susceptibility to changing farming practices.

3.2. Soil Characteristics

Dry land sloping terraces (bari land) on steep to very steep hill slopes, are extremely variable in soil depth and texture which results in variations in their fertility status. Irrigated or partially irrigated terraced level land (khet land) has less variation within a single terrace.

The inherent nutrient holding capacity of the soils is poor, with low nitrogen and cation exchange capacity in the eastern hills (Goldsmith, 1981). Soils are also generally poor in available phosphorus; however, the amount is very often site specific and can vary from low to very high. At higher altitudes, available phosphorus is very low because of the strongly acidic soils which have pH values ranging from 4.7 to 5.9. Since the major minerals are feldspar and mica, the available potassium is medium to very high. Potassium, which is adequately available, is not fully utilized for increasing crop productivity because of the low nitrogen content of the soils. The acidic nature of the soil also hinders the availability of certain macro and micro nutrients. Organic matter content increases with increasing altitude and in general varies from 2.20 to 4.75 %. The higher organic matter content at higher altitude may be due to farmers applying higher doses of compost and FYM and lower temperatures which results in lower oxidation rates (Sherchan, 1987).

Information on the micronutrient status of the soils in the hills is limited. Gupta et al. (1989) reported that boron, magnesium, copper, calcium and zinc are deficient in soils of the mandarin growing areas of Dhankuta district. Cabbage and cauliflower crops are already showing signs of boron and molybdenum deficiencies in areas where off-season vegetables and seed crops are being produced.

3.3. Major Plant Nutrients Lost through Erosion

There is a continuing debate as to weather or not erosion is the primary cause of declining soil productivity. Some reports indicate that the erosion from cultivated land is negligible while the major erosion occurs on marginal land, abandoned land and grazing land (Carson, 1986). There is evidence, however, that erosion studies conducted in the hills of Nepal show that rain water erosion can be a major factor (Maskey, 1991), causing heavy soil and nutrient loss annually from slopping terraces (bari land). An estimation of the major plant nutrients lost through rain water erosion is shown in Table 1.

3.4. Nutrient Removal / Uptake

Information is lacking in Nepal on the rates at which nutrients are removed by crops under different cropping patterns and at the same time, for the quantities of nutrients returned to the soil in the form of residues. The nutrient uptake of crops depends upon many factors including the genetic potential of the crop, soil type and soil moisture. Some information on nutrient uptake is presented in Table 2.

Table 1. Nutrients loss through rainwater erosion.

Land type / Land use	Nitrogen kg/ha/yr	Phosphorus kg/ha/yr	Potassium kg/ha/yr	Sources
Maize/millet, bari	55.0	2.53	7.88	Gurung, 1993
Maize + soyabean khet	0.43-0.83	.002-.003	0.07-.17	Maskey, 1991
Rainfed bench terrace	3.8	5.0	10	Carson, 1992
Rainfed marginal land	15	20.0	40.0	Carson, 1992
Grazing land degraded	75	100	200	Carson, 1992

Table 2. Nutrients removed from soils by plants.

Land type	Crops	Grain yield kg/ha	Straw yield kg/ha	N kg/ha	P kg/ha	K kg/ha	Source
bari land	Local wheat	1675	1638	45.0 straw +grain	10.1 straw +grain	19.7 straw +grain	Sherchan, 1991
khet land	Local rice	1500	1500	42.0 straw +grain	8.0 grain	29.0 straw +grain	Carson, 1986

The availability of more precise balance sheets for the major plant nutrients would help to assess whether the present soil fertility management systems are sustainable or not. It has been realized that the present system is in danger and no longer capable of maintaining sustainable crop productivity in the long run. Shrestha (1992) reported some of the indicators of unsustainability in some parts of the eastern hills.

4. OPPORTUNITIES TO IMPROVE PRODUCTIVITY ON A SUSTAINABLE BASIS

Recent research suggests that the current cropping systems may be made sustainable. They also indicate encouragement for the development of sustainable soil fertility management guidelines for a future research strategy. A long-term study conducted on a rice-wheat cropping system indicated that the productivity of rice and wheat can be increased, or at least maintained, if compost/FYM is supplied along with a balanced dose of chemical fertilizer (NPK). The efficiency of the applied nitrogen is increased when compost is applied (Figure 2).

Under mixed, inter and relay cropping systems which are common in the hills, chemical fertilizers have poor residual effects. Yield data from five years of rice cultivation support this view. Application of 60:30:30 NPK kg/ha chemical fertilizers produced poor residual response in the subsequent crops when compared to compost alone or with nitrogenous fertilizer (Figure 3).

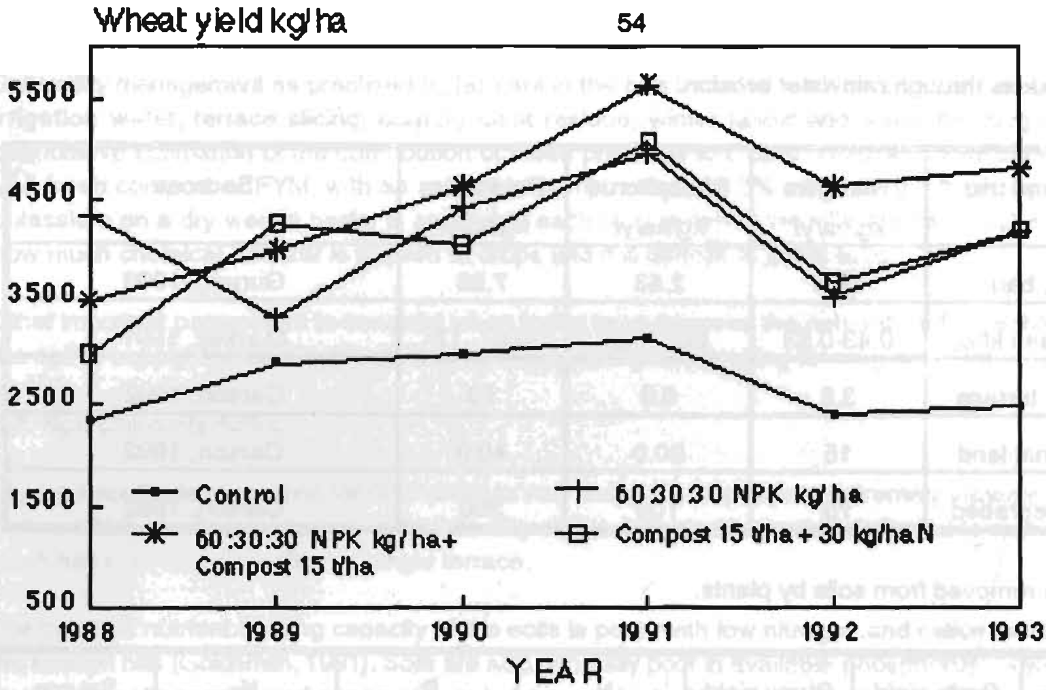


Figure 2. Wheat yield response to organic and inorganic fertilizers over the years.

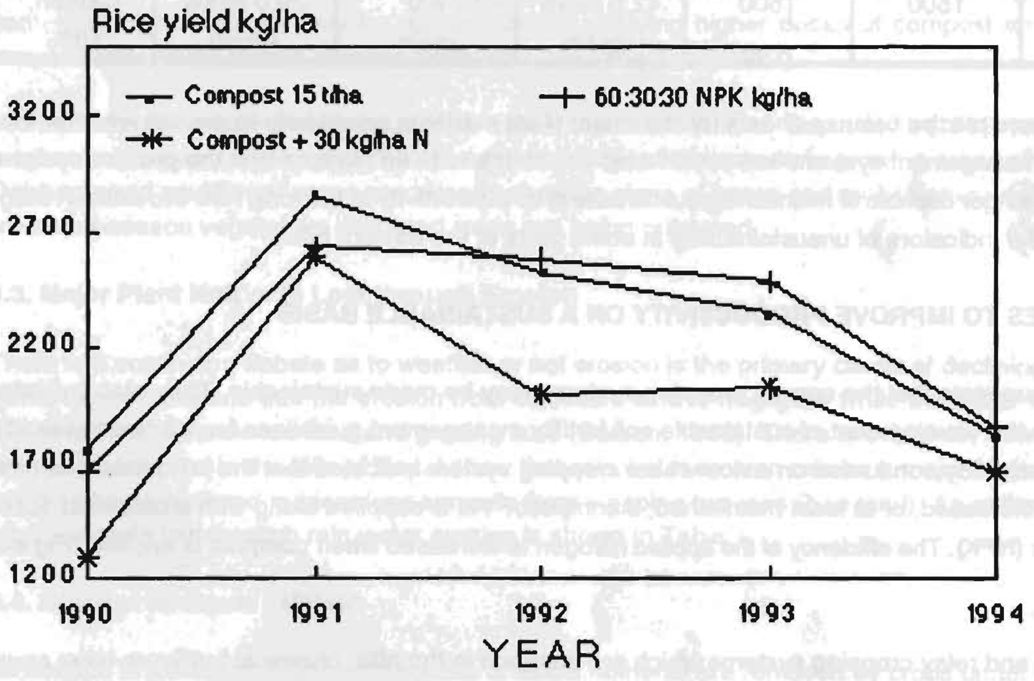


Figure 3. Residual effect on rice of compost and chemical fertilizers applied to the preceding wheat crop.

Millet relayed with maize is the most common cropping pattern in the mid hills of eastern Nepal, where the pattern covers approximately 114,704 ha (67%) of the available cropping area (LRMP, 1986). Experimental results show that chemical fertilizers at 120:60:30 NPK kg/ha alone can not maintain the crop productivity of both maize and millet. The use of compost in combination with chemical fertilizers is necessary if productivity is to be maintained in the long run (Figures 4 and 5).

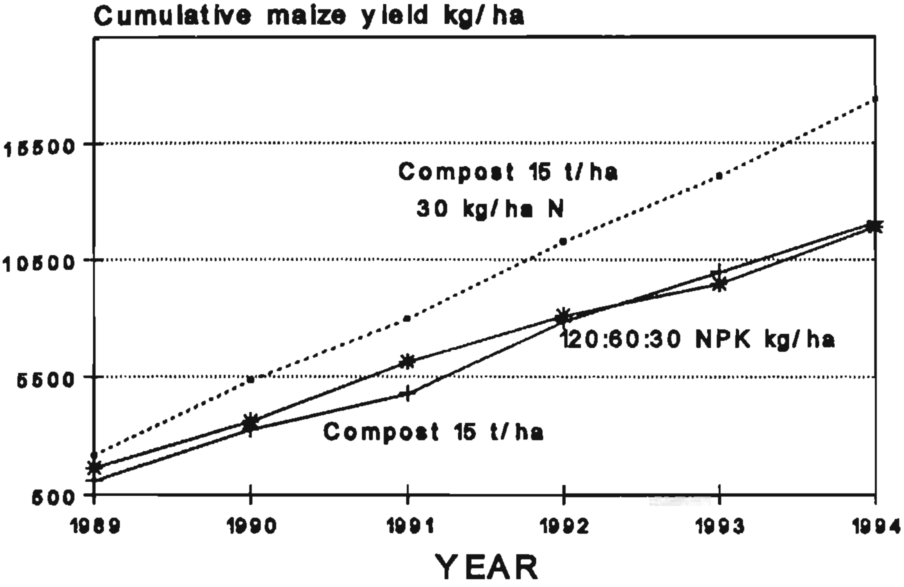


Figure 4. Maize yield response to chemical fertilizers and compost.

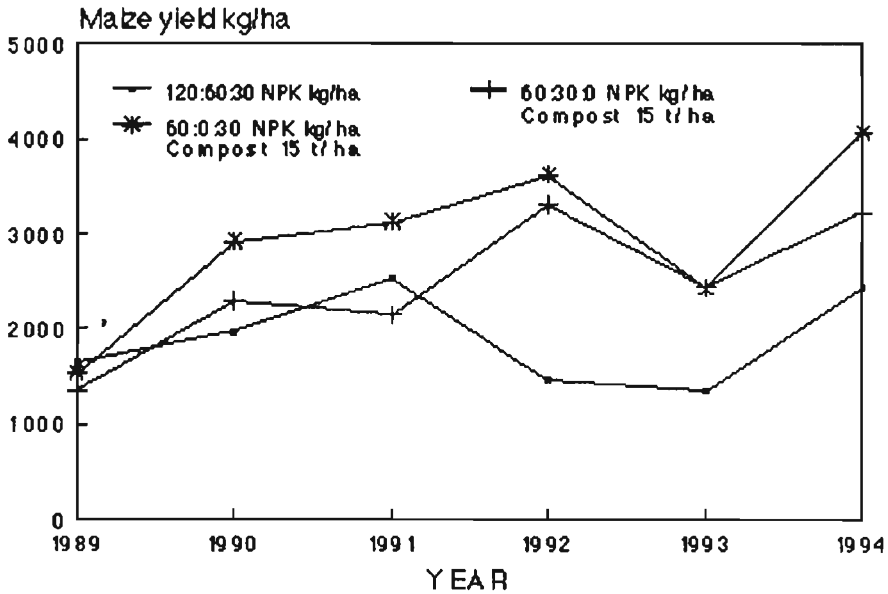


Figure 5. Maize yield response to chemical fertilizers in combination with compost and chemical fertilizer.

Similar to the rice-wheat system, there is also a poor residual effect from chemical fertilizers alone on millet yields in a maize/millet relayed system (Figure 6). From these findings it may be concluded that the release of nutrients from organic sources is more readily available to the succeeding crops, whereas inorganic fertilizers are lost through deep leaching or fixed by clay minerals and therefore become unavailable to plants.

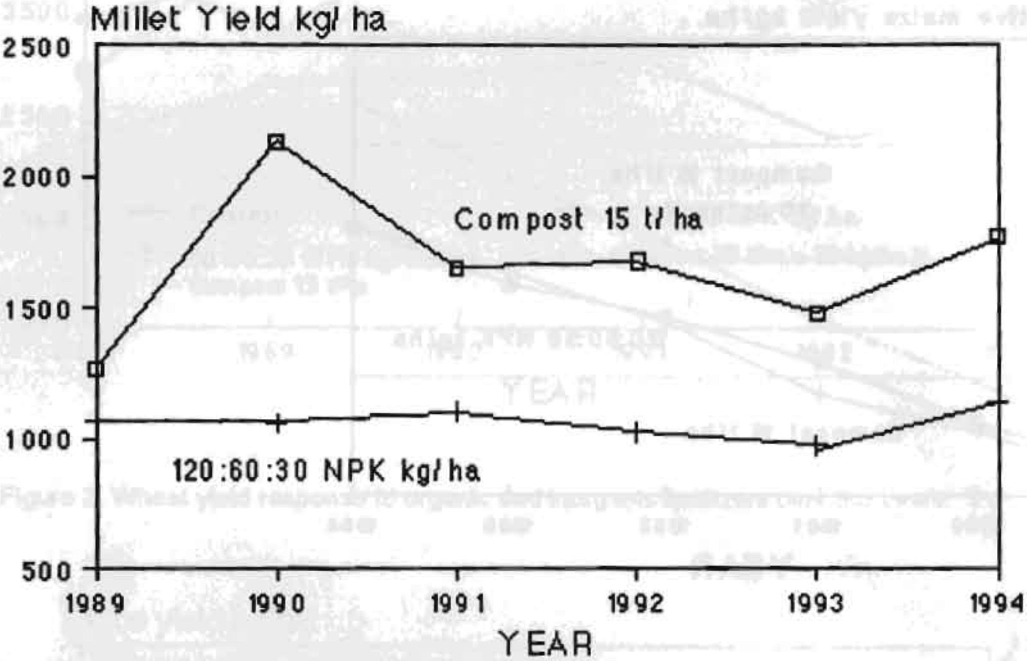


Figure 6. Residual effect on millet of chemical fertilizers and compost applied to the preceding maize crop.

Results of the first five years of long-term experiments on rice-wheat and maize/millet patterns have shown that the combined use of organic and inorganic sources of fertilizer helps to restore soil fertility in the longer term (Tables 3 and 4).

In a rice wheat system, the application of compost has improved the organic matter content, exchangeable calcium, magnesium and CEC of the soil. There is also a strong indication that when chemical fertilizers are applied alone the total exchangeable acidity may increase. There is also an indication of the decreasing availability of DTPA Zn from chemically fertilized plots (Sherchan, 1995).

Under a maize/millet system the lowest pH value (5.3) was found from the chemical fertilizer treated plot and consequently, the total exchangeable acidity was also measured at 1.97 Cmol+/kg. The status of available phosphorus was found to be better when compost and chemical fertilizers (NPK) were applied together. Again, there is an indication of decreasing availability of DTPA iron and zinc from the plots where chemical fertilizers were applied (Sherchan, 1995).

Table 3. Soil properties after 5 years of a rice-wheat long-term trial (mean of three blocks).

Soil pH	5.26	5.15	5.11
Ex. acidity Cmol+/kg	0.69	0.78	0.81
Organic matter %	2.18	1.86	1.94
AVL. phosphorus mg/kg	149.0	78.2	249.0
AVL. potassium mg/kg	65.9	61.9	87.5
CEC Cmol+/kg	9.71	7.28	9.2
Ex. Mg. Cmol+/kg	0.92	0.7	0.96
Ex. Ca. Cmol+/kg	4.54	3.4	4.66
Ex. K. Cmol+/kg	0.06	0.06	0.06
DTPA Extractable			
Iron mg/kg	322.0	218.0	307.0
Manganese mg/kg	28.6	16.1	16
Copper mg/kg	4.7	3.96	4.3
Zinc mg/kg	2.83	1.8	2.4

Source: Sherchan, 1995 (PAC Technical Paper forthcoming)

Note: The initial soil test value of the experiment plot was pH = 5.3, OM % = 1.62, total N = 0.09%, AVL P = 20 mg/kg and AVL K = 78 mg/kg

In the potato+maize systems at high altitude, compost is applied at very high rates; usually not less than 30 t/ha (Gurung, 1991). In order to provide different options to overcome the decreasing availability of plant materials for compost and recognizing that the availability of chemical fertilizers is being increased, an attempt was made to determine the effect on potato tuber yield using a combination of chemical fertilizers (90:60:60 NPK kg/ha, 60:30:30 NPK kg/ha and 30:15:15 NPK kg/ha) and compost/FYM (10 t/ha, 30 t/ha, 50 t/ha and 70 t/ha). Two years of results show that yields were increased by 24, 43, 48 and 49% when 90:60:60 NPK kg/ha was applied in combination with compost at 10 t/ha, 30 t/ha, 50 t/ha and 70 t/ha over the control plot without chemical fertilizers (13.93 t/ha, 15.13 t/ha, 15.28 t/ha and 11.96 t/ha tuber yields). There was an indication that even a small quantity of chemical fertilizers can increase tuber yields significantly but there is no significant effect between various doses of compost (Figure 7).

An alternative to compost is the use of green manures. In the low altitude maize-rice-wheat and rice-rice-wheat cropping systems, *Dhaincha* (Sesbania aculeata), when relayed with maize, increased subsequent rice yields by 23 to 32.5 percent when *Dhaincha* was sown either at the time of earthing up the maize or at the time of hoeing. In both cases, the maize yield was unaffected (Figure 8).

Table 4. Soil properties after 5 years of a maize/millet long-term trial.

Soil Properties	Compost 15 t/ha	120:60:30 NPK kg/ha	60:30:0 NPK kg/ha
Soil pH	5.85	5.35	5.68
Ex. acidity Cmol+/kg	0.63	1.97	0.81
Organic matter %	1.57	1.44	1.6
AVL. phosphorus mg/kg	20.1	12.15	24.18
AVL. potassium mg/kg	62.51	61.87	73.83
CEC Cmol+/kg	12	11.46	12.98
Ex. Mg. Cmol+/kg	1.38	0.96	1.46
Ex. Ca. Cmol+/kg	8.07	6.13	8.25
Ex. K. Cmol+/kg	0.37	0.33	0.37
DTPA Extractable			
Iron mg/kg	103	114.4	87
Manganese mg/kg	123	145	119
Copper mg/kg	2.71	2.62	2.4
Zinc mg/kg	2.96	2.2	1.97

Source: Sherchan and Gurung, 1995 (PAC Technical Paper forthcoming)

Note: The initial soil test values were pH = 5.3, OM % = 1.9, AVL P = 29 mg/kg and AVL K = 116 mg/kg

5. FUTURE STRATEGIES FOR SOIL FERTILITY RESEARCH IN THE HILLS

In the hills and mountains of Nepal, research is often conducted in isolation without paying attention to all the components of the farming system. This type of research cannot be successful. An understanding of the socioeconomic factors affecting farmers' decisions is also essential.

Soil fertility management dynamics are intertwined with components of the farming system. The responsibility to develop an appropriate technology does not rest solely with the soil scientist. Research should be coordinated with all disciplines working to improve the productivity of the overall system. The research agenda would be different, but the goal must be to improve soil productivity.

An analysis of the various biological and socioeconomic factors should be the first priority to identify the factors causing reduced productivity levels or constraining agricultural development. To date in Nepal, base line information on soil resources is not available which has caused difficulties in assessing the levels of land degradation, erosion etc.

Though there has been limited research on soil erosion and nutrient losses in the country, available findings indicate that research to mitigate surface erosion as well as to minimize nutrients loss will be of direct benefit. There is also a need to know the tolerance limit of soil loss under such hilly terrain conditions. Diversity in the geology, soils and climate of the hills in Nepal suggests that erosion studies should be undertaken using a watershed approach (Carson, 1985). Chaudhari and Mahato (1987) have indicated that organic matter content could be one of the parameters to assess productivity. They reported that over an 18 year period, soil organic matter content at the Tarahara Regional Agricultural Research Station fell to 52% of the original level (2.29 to 1.51) and suggested this as a principal cause for the declining productivity of the soil.

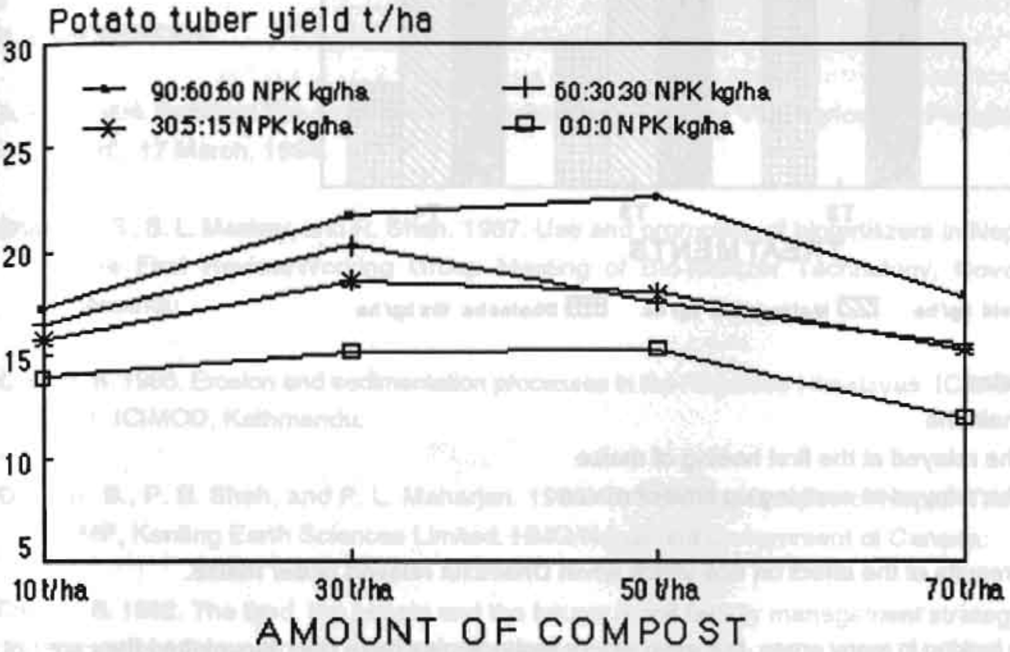
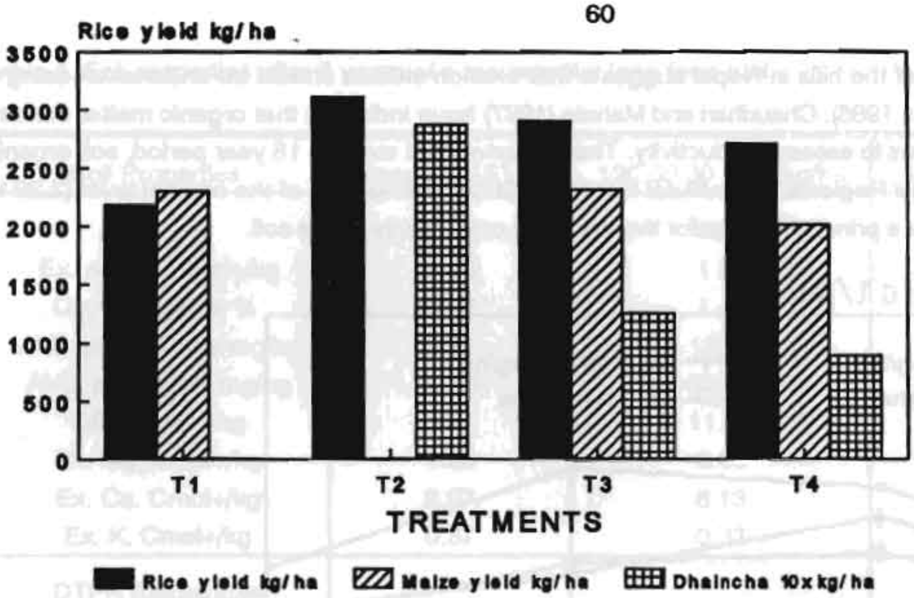


Figure 7. Response of tuber yield to combination of inorganic and organic fertilizers under potato+maize system at high altitude (mean of two years of results).

It has been shown that organic sources of plant nutrients are critical for sustaining soil fertility in the hills. There are two areas where improvements may be made. First, in the supply of farm fodder and forest materials and livestock management systems, and second, in sound production techniques and efficient application of compost/FYM for increasing crop productivity. To achieve this, research should be conducted to gain a better understanding of the dynamics of applying compost alone or in combination with chemical fertilizer. Inconsistent yield responses to Rhizobium inoculum is also an area where research is required.

Identification of research recommendations based on an analysis of biological and social factors is an important area for future work if appropriate research projects are to be developed. Earlier recommendations have been based on altitude differences, namely low (<1100 m), medium (1100 to 1750 m) and high (>1750 m). However, these do not adequately cover the biological and social diversity of the hills.

There is also a need to identify potential areas where the use of chemical fertilizers would bring significant changes in food production by supplying adequate nutrients or correcting deficiencies, or in those areas where favourable soil moisture regimes would allow maximum response to applied chemical fertilizers.



Note: T1 = Sole maize
T2 = Sole Dhaincha
T3 = Dhaincha relayed at the first hoeing of maize
T4 = Dhaincha relayed at earthing up time of maize

Figure 8. Two years results of the effect on rice yields when Dhaincha relayed under maize.

Research findings are lacking in many areas, but even where technologies have been developed they are not reaching the clients. The technology transfer system in the country should be strengthened to ensure that soil fertility management technologies are adopted by the majority of farmers. Until now, soil management technology has been treated as a complementary package of practices to be provided along with plant genetic materials, but evidence is increasingly showing that farmers do not adopt a whole package for a wide variety of reasons. Now is the time to rethink our approach in order to improve the technology adoption levels.

6. CONCLUSIONS

Recent research suggests that both organic and inorganic fertilizers are important for sustaining soil fertility in the hills, but a major emphasis should be placed on improving biologically-based technologies. At the same time, conservation and efficient utilization of natural resources: land, forest and water, are key issues in the research and development process. However, the use of chemical fertilizers cannot be ignored in the present context for meeting high food demand due to a growing population. The human dimension should not be forgotten while designing research strategies. Any strategy should identify the domain where a maximum response to applied inputs, both organic and inorganic fertilizers, can be obtained.

7. ACKNOWLEDGEMENTS

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