Biophysical and socio-economic tools for assessing soil fertility: A case of western hills, Nepal

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Abstract

The middle mountain region of Nepal, which occupies some 30% of the total land, is the homeland of 45% of the total population, with agriculture being the main source of their livelihoods. Hill farming is primarily based on organic manure with livestock, forest and crops being major components of an integrated system. The aim of this study is to develop and promote improved methods for research and development organizations to identify cost-effective and appropriate soil fertility management strategies through; providing an improved understanding of the biophysical and socio-economic factors affecting the adaptability of sustainable soil management strategies in hillside systems, developing methodologies for evaluating soil fertility technologies and management systems for differently resource farmers in different farming systems, and strengthening the capability of local professionals in collaborating institutions to provide useful information to farmers. The work is placing emphasis on promoting cost-effective methods of soil fertility management, building on farmers' own knowledge and systems. Participatory techniques have been used for gaining a better understanding of fertility indicators, trends and existing soil management practices during 2000/01 in the western hills of Nepal. Farmers are now concerned that increasing amounts of chemical fertilizer at increasingly higher cost have to be applied, soils are becoming “harder” and production is declining. As a result farmers in four agro-ecological zones opted to either test methods for “improving” the quality of farm yard manure (FYM), or “improve” crop residue management. Early results show that through covering the FYM with black plastic sheets, yield increases of over 30% can be achieved. The use of participatory farm management techniques is providing a basis for local NGOs and farmers to evaluate their own experiments and develop soil fertility technologies and systems for their environments.

Keywords: Soil fertility, biophysical and socio-economic tools, participatory methods

Introduction

Hill farming systems of Nepal are characterized by the interdependence of crops, livestock and forest use. Crops and livestock are inextricably linked with forest as the resource base by which crop and livestock production are sustained. This interdependence of resource use has been a key to cycling of nutrients. However, changes or pressures on these components effects soil fertility (Gregory, 1999). Nepal has the highest density of livestock per unit area cultivated area in upland parts of the world (Sharma and Subedi 1994) with FYM or compost being the major source of nutrients for agriculture. Among important recent changes are a reduction in livestock numbers, forest degradation, and reduced availability of labor, development of community forest and stall-feeding of cattle. (Turton *et al.*, 1996). Hills cover a range of agro-ecological zones within which agricultural production is determined by a combination of altitude (400-3500 m), rainfall (1500-5000 mm, per annum) and aspect of the topography. As a result, climate varies from sub-tropical to alpine within close proximity with the range of possible crops and other farm enterprises reflecting this variability. In the mid hills, the cropping systems are predominantly maize-based on rainfed uplands and rice-based on lower irrigated lowlands. Double cropping is the norm, with finger millet grown either sequentially or in relay with maize, and partially irrigated wheat grown after rice (Tripathi 2001).

The farming system and socio-economic conditions are stratified by ethnic group (Floyd *et al*, 1999) with Brahmin and Kshetri groups predominating in the low and middle hills, and Gurung and Magar groups predominating in the high hills. Occupational castes are found throughout. The Brahmin/ Kshetri and Gurung/Magar groups are more oriented towards agricultural production for their livelihoods than occupational castes. Farmers' concern about long-term soil fertility is widespread and well founded (Sthapit *et al.*, 1988, Vaidya *et al.*, 1995, Mathema *et al*., 1999). Many farmers feel that continuous application of chemical fertilizers without addition of FYM is causing the soil to deteriorate and that crop productivity is consequently declining (Mathema, 1999). Soil and nutrient losses by erosion and leaching have also been contributing to a decline in soil fertility (Tripathi *et al.*, 1999a and 1999b).

The objectives of our work is to provide an improved understanding of the biophysical and socio-economic factors affecting soil management in hillside agriculture and to develop tools for evaluating alternative soil fertility management systems that will strengthen the capacity of local development professionals to provide useful information to the farmers.

Methodology

Scientific analysis

Two hundred and sixty one composite surface soil samples (0-20cm) from river basin, low, mid and high hills of both rainfed upland and low land rice were collected during 2000-2001 from the different locations of the western hills of Nepal. Information on altitude, aspect, landform, land type, soil colour, drainage, soil type, fertility rating and distance from road were gathered. These parameters were given different ratings in order to analyze, their effects on crop production and soil fertility. Soil samples were air dried, crushed and passed through a 2mm sieves. Soil pH, organic carbon, total N, available P, exchangeable K and available B were analyzed in the laboratory of ARS Lumle. Available micro-nutrients (zinc, iron, manganese and copper) were analysed in Cemat water laboratory, Kathmandu using standard methods.

Farmers' perception of soil fertility

Participatory Rural Appraisal (PRA) was conducted at four different agro-climatic zones: Bhakimli (high hill, 600-2200m), Upper Pakuwa (1000-1600m, mid hill), lower Pakuwa (600-1000m, low hill) and Chambas (<600m, river basin) of western hills to gain an appreciation of farmers' views on soil fertility indicators, management practices, soil fertility and crop productivity trends. In each area, 15-20 male and female farmers participated in focus group discussions and as part of the participatory process were invited to test those improved soil fertility management options that they considered were suitable for their conditions. Theses included:

Improving the quality of manure and crop residue management

Organic manure mixed with bedding materials is the main source of nutrients, but the quality of manure can be improved. 10 farmers from each site tested the existing heap or pit method of preparation of manure with manure covered with a black plastic sheet. Every day over the period November 2000 to February 2001, each farmer put equal amounts of manure under the plastic or into the open pit or heap.

After three months of preparation, manure samples were collected from each farmer for each method, just prior to application to either maize or upland rice crops. Analysis for pH, N, P and K was undertaken. In total 30 samples (10 from each) were analysed. In addition some farmers, 10 in Chambas and 10 in Bakimili opted to compare leaving the roots in the ground with uprooting the legume crop (blackgram and peas) before maize planting. In both cases grain and straw yields were measured.

Farmers evaluation

Farmer's field days were organized in each area to allow wider farmer evaluation of the treatments in during July and August 2001. During the field days, representatives of the District Agriculture office, NGOs, Chairmen of the Village Development Committees, High School Heads and district level media representatives were also present. At each site, 3 to 4 groups of farmers (male + female) commented on the field observations. After the field visit group leaders presented their group findings or comments.

Results and discussion

Scientific analysis

Followings were the scientific parameter to assess soil fertility parameters:

Effect of altitudes on plant nutrients

Soil pH, organic carbon, total N, available P and exchangeable K were affected by altitudes (P=<0.001). The highest pH (6.1) was recorded at <600 m altitude. Organic carbon, N, P and K values increased at higher altitude (Table 1-2). Altitude did not affect the micronutrients (Zn, Fe, Mn and Cu) except B (P=0.05), which increased at higher altitudes (Table 1-2).

Table 1. Effect of altitudes on macro plant nutrients in the western hills

Altitudes	pH	OC (%)	Total N (%)	Available P (mg/kg)	Exch. K ($cmol_c$/kg)
<600 m	6.05	1.07	0.15	30.2	0.40
600-1000 m	5.80	1.59	0.17	43.8	0.32
1000-1600 m	5.64	2.24	0.22	98.1	0.42
1600-2200 m	5.66	2.90	0.27	202.2	0.45
Mean	5.79	1.95	0.20	93.6	0.40
SEM±	0.11	0.13	0.01	18.1	0.06
P value	0.001	<0.001	<0.001	<0.001	0.10

Table 2. Effect of altitudes on micro plant nutrients in the western hills

Altitudes	Available Zn (mg/kg)	Available Fe (mg/kg)	Available Mn (mg/kg)	Available Cu (mg/kg)	Available B (mg/kg)
<600 m	0.91	174.0	46.3	1.29	0.50
600-1000 m	1.05	179.4	55.9	1.42	0.55
1000-1600 m	0.87	194.6	61.5	1.59	0.65
1600-2200 m	0.85	174.2	68.4	1.68	0.66
Mean	0.92	180.6	58.0	1.50	0.59
SEM±	0.16	10.5	10.5	0.29	0.07
P value	0.56	0.10	0.30	0.56	<0.05

Effect of land types of plant nutrients

Organic carbon, available P, exchangeable K, available Fe, Mn and B differed significantly (P=0.01 to 0.001) (Table 3-4) between low land rice and rainfed upland. But pH, total N, available Zn and Cu were not significantly different between low land and rainfed upland (P = 0.11 to 0.44). Organic carbon, available P, exchangeable K, available Fe, Mn and B in soil was significantly higher in rainfed upland as compared to low land indicating that rainfed uplands are more fertile than low lands.

Table 3. Effect of land type on macro plant nutrients in the western hills

Land type	pH	OC (%)	Total N (%)	Available P (mg/kg)	Exch. K ($cmol_c$/kg)
Khet	5.72	1.82	0.20	63.3	0.22
Bari	5.80	2.13	0.21	116.1	0.52
Mean	5.76	1.98	0.21	89.7	0.37
SEM±	0.070	0.123	0.010	14.7	0.036
P value	0.32	0.013	0.114	<0.001	<0.001

Table 4. Effect of land type on micro plant nutrients in the western hills

Land type	Available Zn (mg/kg)	Available Fe (mg/kg)	Available Mn (mg/kg)	Available Cu (mg/kg)	Available B (mg/kg)
Khet	0.98	163.4	30.4	1.41	0.51
Bari	0.88	195.5	78.3	1.58	0.65
Mean	0.93	179.5	54.4	1.50	0.58
SEM±	0.112	7.2	6.7	0.20	0.05
P value	0.34	<0.001	<0.001	0.4	0.004

Participatory analysis

Participatory bases soil fertility analysis by different communities in Nepal is knowledge based perception some of which are as listed:

Farmers' perception of soil fertility

Focus group discussions identified a number of key indicators of higher and lower soil fertility (Annex 1). Farmers use a variety of criteria to classify soils with soil colour being important. Black soils for instance are considered to have better moisture retention, internal drainage and texture, making management practices such as labour, compost, and fertilizer application easier and giving higher yields. This is consistent with the work of Tamang (1996) who reported that soil colour, texture, depth consistency, internal drainage and moisture retention capacity, temperature regime, slope, aspect and elevation and management implications (source of water, labour requirement compost and/or chemical fertilizer required and yield) were factors, considered by farmers when classifying soil. He also pointed out that the physical characteristics of the soil determine management practices. With sufficient water, compost, labour and a suitable climate and appropriate management, any soil can be made fertile and productive. The darker the soil, the more organic matter is present and the more fertile the soil is likely to be. Another key indicator mentioned by farmers is increasing hardness of the soil, which become harder and cloddier when inorganic fertilizers are applied. This requires an increased number of ploughing and increased uses of inorganic fertilizer to maintain production.

Soil fertility management practices

Four principle soil management practices were identified: manure mixed with bedding materials, compost made from leaf litter, legumes either grown on their own or intercropped and chemical fertilizers although there were slight differences between the three areas. Manures were regarded as the best source of soil fertility, chemical fertilizers ranked second, compost third and legumes fourth (Annex 2), although in those areas closer to markets chemical fertilizers were preferred. Work is shared between men, women and children but the degree of involvement varies according to the nature of work (Turton et al., 1996). Collection, processing transportation and application of materials for soil fertility management is largely women's work (Tamang, 1992). Organic fertilizers are generally prepared and applied by women, with purchase and distribution of chemical fertilizers largely conducted by men, (Kiff et al., 1995). Men play a key role in trapping flood water, turning the FYM/compost heap and work related to the cattle shed and ploughing.

Reasons for declining productivity

Causal diagram (not shown in the text) derived from focus group discussions indicate that the main causes of declining soil productivity were a lack of manure, low use of chemical fertilizers and more erratic rain. Other primary reasons included an increase in cropping intensity. The reasons for lack of manure included a decrease in labour availability due to migration and children being at school, decreasing livestock due to inadequate fodder, cash and labour to look after the livestock. The reasons for low use of chemical fertilizer included high cost, non-availability at key times and a lack of knowledge of their use.

Trends in soil fertility

Farmers expressed their view that 30-40 years ago, only local rice was grown in irrigated lowlands and only local maize and finger millets in rainfed uplands, but in recent years wheat has been included in both low lands and rain-fed uplands systems. In the past animals were grazed on fallow but have now had to be controlled. Livestock numbers have decreased and labour availability has declined due to increased migration with most children now attending school. This has led to a decline in manure availability and an increased in the use of urea and di-ammonium phosphate (DAP). As a result crop productivity was decreasing.

Other surveys (Subedi et al., 1989; Carson, 1992, Turton et al., 1995) identified lack of adequate FYM or compost as a major factor limiting productivity. There were widespread reports from farmers of decreasing crop yields (Subedi and Gurung, 1991 and Tamang, 1993), although yields are more stable on low land rice (Turton, 1996). At the same time others have indicated an increase in yields on rainfed uplands (Joshi et al., 1994 and Turton et al., 1995). A survey (Shrestha et al., 2000) showed very mixed views. Productivity was considered to increasing, decreasing or stagnant in different situations. The reasons for an increase were primarily use of improved seed and use of fertilizer (organic and inorganic); for a decrease, declining soil fertility due to lack of or poor use of chemical fertilizer, unavailability of sufficient quantities of manure; and for stagnant productivity, traditional farming practices such as use of local seeds and no effect of chemical fertilizer.

Improved manure treatment and crop residue management

Eighty farmers took part in field days at Chambas and 35 farmers each at Pakuwa and Bhakimli. All groups reported similar findings after field visits. Farmers indicated that a darker colour, different smell, temperature rise, heavier weight, and improved mixing with soil during incorporation have led to improved productivity. They remarked that covered manure resulted in better crop growth. Similarly the residual effect of the previous season's legume (black gram or peas) showed better crop growth than where legume roots had been removed. This indicates that previous season legume roots enhanced soil fertility, which was observed in the crop growth of the current season.

Nutrient analysis showed that manure prepared by covering with plastic sheet has a lower pH, higher N and K and similar P content. Farmers commented that two-month plastic covered manure is equivalent to ten-month uncovered manure, indicating much faster decomposition with covered manure. Final yield results indicated over 30% yield increase from the covered manure and up to 10% yield increase from leaving legume roots in the soil.

Future activities

Farmers are being encouraged to continue experimenting with alternative soil fertility management options to enable them to make informed decisions on what is appropriate for their circumstances. At the same time farmers' soil fertility indicators are being validated through soil nutrient analysis to facilitate better linking of farmers' knowledge with that of scientists. From this, tools for the better assessment of alternative soil fertility management will be developed.

Conclusions

Altitude, land types, aspect and soil colour and texture have significant effect on plant nutrients. Farmers' local knowledge on soil fertility needs to be incorporated in the development of improved soil fertility management programs of hill farming systems. Manure, chemical fertilizers, compost and legume crops form an integrated package of soil management practices for maintaining or increasing productivity. The use of simple in-expensive practices such as improved manure and crop residue management can enhance nutrient efficiency. At the same time soil fertility and crop productivity depends on the availability labour, manure and fertilizers as well as market in the hills of Nepal.

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Annex 1. Farmer indicators of soil fertility and soil productivity

Indicator	Higher fertility	Lower fertility
Aspect North or south facing	South facing slopes	North facing slopes and shade make soils less productive
Position on terrace	On areas immediately above terrace riser	On areas immediately below terrace riser
Erosion	Where soil has been received as sediment or no erosion is occurring	Where soil has been eroded
Soil colour Rato seto (whithish brown Kalo mato (black) Rato mato (red) Fusro mato (brown) Khairo mato (brownish) Panhelo mato (yellow)	Red soils are the best (*raja*) but difficult to manage Black soils (kaji) are more fertile and easier to manage and give reasonable yields under all conditions. Black and loamy soils are more fertile	Red soils (rato mato) are more susceptible to soil erosion, as the particles are finer than black soils and start moving from the weaker parts of the field Brown soils (*paji*) are poor White soils are infertile
Texture and moisture holding capacity	Clay soils are more fertile when rainfall is high. Clay soils hold more water for longer. Friable soils ("ripe" soils) are more fertile	Loam soils cannot hold water for long.
Stoniness	Less stones indicates higher fertility	Stones appearing indicate soil loss and decreasing soil fertility.
Depth	Deeper soils are more fertile	
Hardiness	Soft, ripe and friable	Hard and cloddy When inorganic fertilizer is used soil becomes harder, cloddy and less fertile. Productivity decreases.
Ease of ploughing	Easier to plough Soil is soft or ripe, few clods,	Difficult to plough The number of ploughings increases with the use of chemical fertilizers. Before using chemical fertilizers two ploughings were sufficient to plant lowland or upland crops but now 3-4 ploughings are necessary for land preparation.
Weeds Karkale or kane Leu (blue green algae) Gundi Nilo buke Bonso (grass) Suire (grass) Charchare Thaunne	More weeds indicates fertile soils Bonso pati, gande, kane and lunde Bonso gives 3 cuts on fertile soils, only one on infertile soils Blue green algae (leu) presence indicates good fertility Napier grass on terrace risers, giving 2 cuts per month	Problem of boke weed in cultivated areas *Banmara* problem in forests Absence indicates lower fertility and farmers will apply DAP Napier will not grow on infertile soils
<u>Productivity</u> Crop colour Crop growth Grain fill Disease, pests and termites Yield Taste	High yields indicate high fertility Crops grow vigorously; have good appearance and colour, more resistant to termites, but more pest and disease damage. Taste is better	Poor plant growth , yellowish colour, poor grain fill, less resistant to termite attack and low yields

Annex 2. Farmer ranking of the main soil fertility management practices

Inputs	Chambas	Lower Pakuwa	Upper Pakuwa	Bhakimli	Overall
Manures Organic matter added to manure	1	2	1	1	1
In-situ manuring	Na	Na	Na	5	5
Composts Primarily leaf litter	3	3		3	3
Legumes Beans, black gram, soya-beans, cowpea, pea, interplanted or relay cropped	3	4	3	4	4
Chemical fertilizers Primarily DAP and Urea	1	1	2	2	2

Note: 1=Best, 5= least, Na= Not applicable