13 THE USE OF BIOPHYSICAL AND SOCIOECONOMIC TOOLS IN SOIL FERTILITY AND ORGANIC MATTER

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Abstract

Agriculture is the main source of livelihood for most people in hillside areas of Nepal, and soil fertility is largely maintained through the use of organic manure. Discussions with farmers indicated five principal soil fertility management practices (manure, chemical fertiliser, compost based on leaf litters, growing legume crops, and in-situ manuring). Farmers identified five soil productivity indicators (crop productivity, soil characteristics (particularly soil colour), management requirement, species of weeds, diseases, and pests, and termites). Historical trends (increasing crop intensification, decreasing livestock numbers, increasing use of chemical fertilisers, reduced labour availability, and change in the climate over the last 30-40 years) showed a decline in soil productivity. Scored causal diagrams on soil fertility drawn from focus group discussions indicated that the primary causes of declining soil fertility and crop productivity are a decrease in available manure, increased cropping intensity, low use of chemical fertilisers, and change in climate.

Scientific evaluation confirmed that altitude, farming system, and land types affected the availability of soil nutrients. Organic C, total N, available P and exchangeable K increased in less intensive farming systems, which were at higher altitudes. These nutrients as well as available Fe, Mn, and B in soil significantly increased in rainfed upland (bari) compared with irrigated lowland (khet). Covering manure with black plastic sheets resulted in faster decomposition as well as increased total N and exchangeable K. Covered manure applied to summer rain-fed maize and upland rice as well as irrigated lowland spring maize increased grain and straw yields between 13% and 36% when compared with uncovered manure.

Both farmers' indigenous knowledge and their criteria were as useful as scientific evaluation in assessing soil fertility improvements. Therefore, farmers' knowledge and criteria should be considered when monitoring soil fertility and crop productivity in farmer trials.

Introduction

The hills of Nepal cover a range of agroecological zones within which agricultural production is determined by a combination of altitude (400-3500 masl), rainfall (1500-

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5000 mm/year) and aspect (Turton et al. 1996). Farming systems in the hills are characterised by the inter-relationship between crops, livestock, and forestry, where soil fertility is largely maintained by application of farmyard manure (FYM) and compost (Sthapit et al. 1989; Riley 1991; Subedi and Gurung 1991; Tamang 1992; Gregory 1995; Turton et al. 1996; Vaidya et al. 1995; Mathema 1999; Shrestha et al. 2000). Trees and crops provide fodder and bedding materials for livestock and livestock provide draft power and manure for crops. Field surveys have shown that application of FYM, compost, chemical fertilisers, and soil nutrients carried down from the forest and villages in the first spring flood water, inclusion of a grain legume in the crop rotation, mulching with weeds, forest litter, or crop residues, use of short fallows, slicing and burning of terrace risers, in-situ manuring, green manuring, burning of trash, and collecting leaf litter are practices used by the farmers to maintain soil fertility in the hills (Suwal et al. 1991; Joshi et al. 1994; Joshi et al. 1995). However, organic manure mixed with bedding materials is the main source of nutrients.

Important recent changes in rural Nepal include: reduction in livestock numbers, forest degradation, reduced labour availability, community forestry development, and stall feeding of cattle (Turton et al. 1996). Many farmers feel that continuous application of chemical fertilisers without addition of FYM is causing the soil to deteriorate and crop productivity to decline (Mathema 1999). Soil and nutrient losses by erosion and leaching have also contributed to a decline in soil fertility (Tripathi 1999; Tripathi et al. 1999). A search for soil fertility improvements needs to incorporate social as well as technical factors if improvements for farmers are to be realised (Gregory 1995).

Hence the objectives of this study were to develop simple robust methodologies for assessing soil fertility taking into account both biophysical and socioeconomic factors. The project has worked closely with farmers using both farmers' and scientific knowledge to assess soil fertility-enhancing technologies that farmers have selected themselves.

Materials and Methods

Farmer evaluations

Farmers' perceptions of soil fertility and selection of soil fertility enhancing treatments

Participatory rural appraisals (PRAs) were conducted in four different agroclimatic zones: Bhakimli (600-2200m, high hill), Upper Pakuwa (1000-1600m, mid hill), lower Pakuwa (600-1000m, low hill), and Chambas (<600m river basin), to gain an appreciation of farmers' perceptions of soil fertility, management practices, and crop productivity trends. In each area, groups of 15-20 farmers (men and women) participated in group discussions and as part of a participatory process were invited to test improved soil fertility management options that they considered suitable for their conditions. Farmers from each of these areas visited the Agricultural Research Station, Lumle (ARS/Lumle) to discuss and view the options available. As a result they chose to test the use of plastic sheets to see if this improved manure quality and increased crop yields as well as to compare leaving legume crop roots in the soil rather than removing them before planting the next crop.

The participatory process included the use of scored causal diagrams, transect walks, pair-wise ranking of alternative soil fertility technologies, historical trends analysis, and resource ranking of farmers. The processes were important for building relationships with farmers that provided further opportunity to work closely with them in a joint evaluation of the soil fertility enhancing options.

Farmers' evaluation during FYM decomposition

This involved continuous assessment of manure decomposition using farmers' criteria, both individually and as groups, to see if there were differences between covered and uncovered FYM. The criteria were colour, smell, moisture content, rate of decomposition, uniformity of manure, temperature, texture (hard or soft), weight of the manure, and some indicator of quality as the manure was moved to the field. During transport from the heap or pit to the field and while spreading and incorporating the manure, farmers noted any increase or decrease in labour requirement.

Testing black-plastic covered and uncovered FYM

In all the four agroecological zones, farmers tested black-plastic covered and uncovered FYM on either summer maize or upland rice in rain-fed upland (bari) and spring maize in irrigated lowland (khet) applied at the normal rates used by farmers This trial was undertaken by 10 farmers in each zone on an area of $100m^2$. During the crop growth period, farmers judged crop performance and recorded their observations at different growth stages. At maturity the crop was harvested separately from each plot and yields recorded. All farmers considered the cost of the black plastic at NRs 50[3] affordable, many indicating that they could in fact use other material that would cost nothing.

Farmers' evaluation during the growth of the crop and mid season

Differences in crop condition were noted (1) at crop emergence – colour and crop stand, (2) at first weeding – plant stand, (3) at tasselling – stem thickness, colour, and size of ear were compared together with any difference in termite damage, and (4) at harvest – the weights of grain and straw were established. Grain and straw yields were sampled from the whole plot and yields/ha determined at 12% moisture content. Further comparative soil analysis was undertaken after harvest to determine any residual soil fertility differences in farmers' plots.

Farmers' field days

Before crop harvest, farmers organised field days facilitated by researchers at each site to show the response of the covered and uncovered manure in upland rain-fed summer maize and upland rice and spring maize. Representatives of the District Agriculture Office, non-government organisations (NGOs), chairmen of the Village Development Committees, high-school head teachers, and district-level media representatives were invited and interacted with local farmers. At each site, three to four groups of farmers (men and women) with a leader nominated by each group presented their group findings.

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[3] In 2002 US$ 1 = NRs 78

Scientific evaluation

Field survey

Two-hundred-and-sixty composite surface soil samples (0-20 cm) were collected representing river basin, and low, mid, and high hills of both rain-fed upland and irrigated lowland. The samples were collected from different areas of Tanahun, Gorkha, Parbat, Myagdi, and Palpa districts. Information on altitude, aspect, land form, land type, soil colour, drainage, soil type, fertility rating, and distance from a motorable road were gathered.

Laboratory analysis

Samples were air dried, crushed, and passed through 2 mm sieves. Soil pH (1:2.5, soil:water), organic C (Walkley-Black), total N (Kjeldahl), available P (Bray and Kurtz), exchangeable K (1M ammonium acetate extraction), and available B (hot water extraction) were analysed in the laboratory of ARS/Lumle. Available micronutrients (Zn, Fe, Mn, and K) were analysed in Cemat Water Laboratory, Kathmandu, Nepal, using an atomic absorption spectrophotometer.

Testing improvements in the quality of FYM

Existing manure heaps or pits were divided into two equal halves. Half of the FYM was covered with a black plastic sheet and the remaining half was left uncovered as normal. Each day from November 2000 to February 2001, farmers placed equal amounts of FYM either under the plastic covered or on the uncovered pits or heaps. Comparative nutrient analysis of covered and uncovered FYM was made at the time of FYM application in the field. In March, after 3 months of preparation, plastic-covered and uncovered FYM samples were collected from each farmer before field spreading and analysed for pH, and N, P, and K content. In total, 40 samples (10 from each area) were analysed in Lumle laboratories. At the same time soil samples were analysed for each farmer's test plot before the manure was spread to ensure that there were no major differences in soil fertility between treatment plots.

Results and Discussion

Participatory analysis

Farmers' perception of soil fertility management

The group discussions identified five principal soil fertility management practices, namely manure mixed with leaf litter and bedding (FYM), composts (primarily leaf litter), legumes either grown on their own or intercropped, chemical fertilisers, and one method of in-situ manuring sometimes used in Bhakimli but now declining in practice. Although there were slight differences between the four areas, FYM was regarded as the best source of soil fertility, chemical fertilisers ranked second, composts third, and legumes fourth (Table 13.1).

At Chambas and Lower Pakuwa, chemical fertiliser was given as high as or higher priority than manure, as a result of more intensive cropping systems and greater

Table 13.1: **Summary matrix ranking of the main soil fertility management practices**					
Inputs	**Chambas**	**Lower Pakuwa**	**Upper Pakuwa**	**Bhakimli**	**Overall Rank**
Manure					
Organic matter added to manure	1	2	1	1	1
In-situ manuring	NU	NU	NU	5	5
Compost					
Primarily leaf litter	3	3	-	3	3
Legumes					
Beans, black gram, soybean, cowpea, pea, interplanted or relay cropped	3	4	3	4	4
Chemical fertilisers					
Primarily DAP and urea	1	1	2	2	2
Note: 1=most preferred, 4=least preferred, NU=not used, DAP = diammonium phosphate					

availability of khet land. Where bari land predominated, manures were seen as the best option. The use of compost was seen as necessary to supplement when FYM and chemical fertiliser were unavailable or unaffordable.

Farmers' indicators of soil fertility

Focus group and individual farmer discussions in the case study areas provided more detail with farmers' descriptions of higher and lower soil fertility and productivity against each indicator. It was confirmed that farmers use a variety of inter-related criteria to characterise their soils with soil colour being dominant. Other factors included texture, depth consistency, internal drainage and moisture retention capacity, temperature regime, slope, aspect and elevation, and management implications (such as source of water, labour requirement, compost and/or chemical fertiliser required, and yield), all related to soil health and production potential. In fact, farmers considered that with sufficient water, manure, and labour, and a suitable climate and appropriate management, any soil can be made fertile and productive.

Pair-wise ranking of these criteria by farmers provided detail on the priorities for each indicator. This differed slightly from area to area but overall the highest ranking was given to indicators associated with crop productivity, especially crop growth, followed by soil characteristics, especially soil colour and hardness, management requirements, pests, and manure requirement (Table 13.2).

Productivity trends observed by farmers

Historical trends observed by farmers included (1) increasing intensification over the last 30 years; (2) decreasing livestock numbers and therefore insufficient manure for all crops; (3) increasing use of chemical fertilisers with increasing problems of soil hardness and ploughing difficulties; (4) reduced labour availability due to children being at school, young people not wanting to work on farms, increasing migration, and an ageing rural population; (5) an increase in pests due to intensification; and (6) a change in climate with rain no longer falling at the most optimal time, resulting in increased soil erosion (Box 13.1).

Table 13.2:	Indicators and ranking identified through pair-wise ranking in farmer discussion groups						
	Indicator	**Lower Pakuwa**	**Upper Pakuwa**	**Chambas**	**Bhakimli**	**Average**	**Overall Rank**
Crop productivity	Crop yield	2	6	3	3	3	1
	Crop growth and colour	4	1	1	1	2	
	Grain fill	1	3			2	
	Late rice/early maize	8	3			8	
	Taste of grain		3			3	
Soil characteristics	Soil colour	3	6	3	3	4	2
	Soil depth		8			8	
	Soil hardness	10	5	6	3	6	
	Soil moisture	8	1	7	6	5	
Management requirements	Ease of work	4				4	3
	Labour requirement	6	10			8	
	Ploughing time			1		1	
	Manure requirement	6				6	
Indicator species	Weeds	10	9	3	2	6	4
	Diseases and pests		10	9	7	8	
	Termites			8		8	
Note: 1=most preferred, 10=least preferred							

Reasons for declining productivity

Scored causal diagrams derived from focus group discussions held in each agroecological site indicate that the primary causes of declining productivity and soil fertility were a decrease in manure availability (ranging from 50-75% depending on area), increased cropping intensities (30%), low use of chemical fertilisers (10-25%), and a change in climate (more erratic rainfall). Other primary reasons included an increase in cropping intensity with reduced fallows, lack of irrigation (at Chambas, Tanahun), and low adoption of improved technologies.

An example from Lower Pakuwa shows the relative percentages of causal factors for each primary cause (Figure 13.1). In this situation, the reasons for lack of manure included lack of labour (18-50%) (due to out migration, children being at school, and young people not wanting to work on farms), and insufficient livestock (due to inadequate fodder, cash, and labour to look after the livestock). The reasons for low use of chemical fertiliser (10-25%) included high cost, non-availability, transport problems, increased soil hardness, the need to apply increasing quantities, as well as inadequate knowledge of their use.

The views of men and women were difficult to distinguish because they wished to participate and contribute as a community rather than as sub-divisions of their communities.

Box 13.1: **Historical trends**

Intensification

- 30 years ago only rice was grown on khet land and maize-millet on bari land. Now there are three crops on khet (rice, maize and wheat) and three crops on bari (maize, millet, wheat).
- With one crop, production was very good; as more crops have been grown, productivity has declined. The increase in crop production occurred as a result of rapid population growth.
- 30-40 years ago, there was fertile soil due to high organic matter but now it has decreased due to deforestation.

Livestock Numbers

- 30-40 years ago there were more livestock. The rich had many animals but everyone has the same now.
- Farmers used to apply only organic fertiliser but now farmers are using chemical fertiliser.
- Animals used to be grazed on fallow lands, now they are controlled.
- Lack of grazing land has caused a decrease in number of livestock.
- Due to community forestry restrictions the number of livestock has decreased. Animals are all stallfed now.
- There is insufficient manure for all crops, so rice yield has decreased compared with 30 years ago.

Chemical Fertilisers

- Soil becomes bad if only chemical fertilisers are applied. If both manure and fertiliser are applied it is good for soil fertility.
- Now DAP and urea are used for wheat.
- When urea is used alone in high quantities, the crop lodges but with a mixture of FYM and urea, there is a good crop. If urea is not used, there is low yield.

Labour Availability

- Labour has decreased due to children being at school. Young people do not want to work in the field.
- More people migrate looking for work.
- Now there are only old people living in the villages.

Change in Climate

- Rain no longer falls at the most optimal time. There used to be more winter rain and snow.
- 30-40 years ago, it used to rain on time but now the weather is reversed.
- Hailstones sometimes damage crops.
- Soil erosion is increasing.

Increase in Pests

Insect pests have increased because three crops are now grown per year.
Crops do not ripen well because of high cropping intensity.
Post-harvest losses have increased.

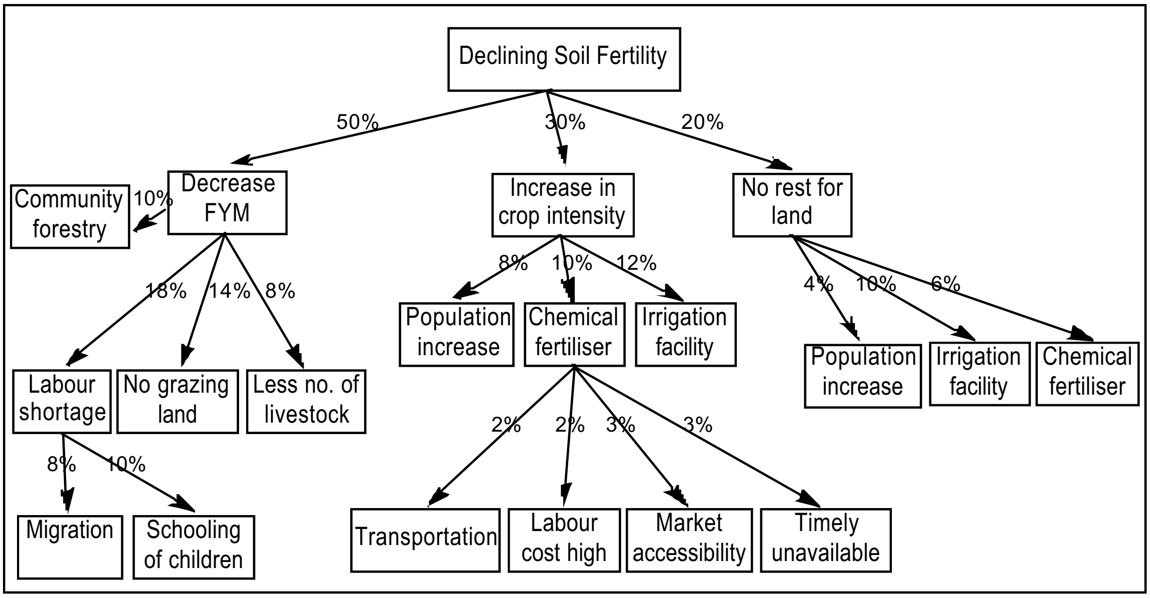

Figure 13.1: Scored causal diagram (Lower Pakuwa, Parba)

Farmer's field days

Eighty farmers took part in farmers' field days at Chambas and 35 farmers each at Pakuwa and Bhakimli. The group leaders at the three sites reported similar comments after visiting the field demonstration. They indicated that the covered manure resulted in better crop growth than the uncovered manure and that residual effects of the previous season's legume roots (black gram and peas) resulted in better crop growth than when legume roots had been removed. This indicates that the roots of legumes enhanced soil fertility from the previous season.

Scientists' evaluation

Impact of altitude and farming system on plant nutrients

This is not the effect of altitude, it is the impact of altitude on the farming system, which influences use and therefore nutrients. As altitude increases, the temperature decreases and the cropping intensity decreases. Thus the utilisation of plant nutrients slowly decreases as we go higher up. Soil pH, organic C, total N, available P, and exchangeable K were affected by altitude and the farming system at that altitude (P=<0.001). The highest pH (6.1) was recorded at <600m altitude. Organic C, N, P and K values increased at higher altitude (Table 13.3). Altitude did not affect the micronutrients (Zn, Fe, Mn, and Cu) except B (P=0.05), which increased at higher altitudes.

Effect of land types on plant nutrients

Organic C, available P, exchangeable K, and available Fe, Mn, and B differed significantly (P=0.01-0.001) (Table 13.4) between lowland and rain-fed upland; but pH, total N, and available Zn and Cu did not (P = 0.11-0.44). Organic C, available P, exchangeable K, and available Fe, Mn, and B in soil were significantly higher in rain-fed upland than in lowland, indicating that rain-fed uplands are more fertile than lowlands

Table 13.3: **Plant nutrients at different altitudes in the western hills**										
Altitudes m	**pH**	**Organic C (%)**	**Total N (%)**	**Avail-able P (mg/ kg)**	**Exchange-able K (cmol/kg)**	**Avail-able Zn (mg /kg)**	**Avail-able Fe (mg/ kg)**	**Avail-able Mn (mg/ kg)**	**Avail-able Cu (mg/ kg)**	**Avail-able 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
SD	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	<0.001	0.10	0.56	0.10	0.30	0.56	<0.05

Table 13.4: **Effect of land type on plant nutrients in the western hills**										
Land type	**pH**	**Organic C (%)**	**Total N (%)**	**Avail-able P (mg/ kg)**	**Exchange-able K (cmol/kg)**	**Avail-able Zn (mg /kg)**	**Avail-able Fe (mg/ kg)**	**Avail-able Mn (mg/ kg)**	**Avail-able Cu (mg/ kg)**	**Avail-able B (mg/ kg)**
Khet	5.72	1.82	0.20	63.3	0.22	0.98	163.4	30.4	1.41	0.51
Bari	5.80	2.13	0.21	116.1	0.52	0.88	195.5	78.3	1.58	0.65
Mean	5.76	1.98	0.21	89.7	0.37	0.93	179.5	54.4	1.50	0.58
SD	0.070	0.123	0.010	14.7	0.036	0.112	7.2	6.7	0.20	0.05
P-value	0.32	0.013	0.114	<0.001	<0.001	0.34	<0.001	<0.001	0.4	0.004

Testing quality improvement of manure

Mean N, P, and K content of each of the ten samples of covered and uncovered manure at Chambas, Pakuwa, and Bhakimli are presented in Table 13.5. Manure analysis indicated that N, and K content tended to be higher in covered manure, confirming that covering manure did enhance the nutrient content, most probably through a reduction in gaseous and moisture losses. P content was similar in both the samples. Farmers indicated that 3-month-old covered manure was equivalent to 10-month-old uncovered manure indicating faster decomposition when covered.

Table 13.5: **Mean, N, P, and K content of plastic covered manure and uncovered manure at four agroecological zones**						
Agroecological zones	**N (%)**		**P (%)**		**K (%)**	
	Covered	**Uncovered**	**Covered**	**Uncovered**	**Covered**	**Uncovered**
Bhakimli (high hill)	2.19	2.07	0.62	0.57	1.99	1.98
Upper Pakuwa (mid hill)	1.56	1.3	0.38	0.34	1.93	1.79
Lower Pakuwa (low hill)	1.57	1.44	0.37	0.41	1.81	1.38
Chambas (river basin)	1.42	1.39	0.58	0.58	1.87	1.68
Mean	1.69	1.55	0.49	0.48	1.90	1.70

Effect of covered and uncovered manure on crop yields

Covered manure produced significantly higher yields on bari land (7.01 t/ha) than uncovered manure (6.05 t/ha) at Bhakimli (Table 13.6). Similarly, significantly higher yields of maize on bari were recorded with covered manure at Upper Pakuwa (1.44 t/ha compared with 1.06 t/ha for uncovered manure). However, spring maize grain yields on khet at Lower Pakuwa were not significantly increased although covered manure overall gave on average a greater yield (2.99 t/ha compared with 2.65 t/ha). At Chambas, upland rice grain on bari using covered manure gave a significantly higher yield (3.34 t/ha compared with 2.77 t/ha). An increase in straw yields was also noted.

Table 13.6: **Mean grain and straw yields of summer maize in bari (Bhakimli, Upper Pakuwa), spring maize in khet (lower Pakuwa), and summer upland rice in bari (Chambas)**

Agroecological Zones	Grain Yield (t/ha)		Straw Yield (t/ha)	
	Covered	Uncovered	Covered	Uncovered
Bhakimli (bari)	7.01	6.03	-	-
Upper Pakuwa (bari)	1.44	1.06	9.82	7.48
Lower Pakuwa (khet)	2.99	2.65	10.24	8.33
Chambas (bari)	3.35	2.77	3.84	3.29
Mean	3.70	3.13	7.96	6.37

Conclusions

We can draw three sets of conclusions from this work.

Farmers have an in-depth knowledge of their soils; they use a large number of inter-related indicators related to crop growth, soil characteristics, and management requirements for planning and managing their crops. They are also aware of the factors contributing to declines in soil and crop productivity and are keen to try out soil fertility-enhancing technologies appropriate to their situations. As a result farmers selected low-cost soil fertility-enhancing options to improve crop productivity.

Manure prepared by covering with black plastic and applied to rain-fed summer maize and upland rice as well as irrigated spring maize increased grain as well as straw yield by 13-36% and 17-31% respectively. Leaving pea root residues in the soil (not uprooting) increased both maize and stalk yields by 26% and 3% respectively in the high hill conditions of Bhakimli (Myagdi). Organic manure/compost is necessary for conserving soil moisture, maintaining soil fertility, and sustaining or increasing crop productivity in maize-finger millet, rice-wheat, and upland rice-black gram systems.

Farmers' assessment and scientists evaluation of soil fertility management led to similar conclusions. This means that farmers' criteria can and should be used in farmer testing of soil fertility enhancements.

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