Changing Soil Fertility Management in Bhutan: Effects on Practices, Nutrient Status and Sustainability[*]

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Abstract

This paper is the results of a Soil Fertility Management (SFM) survey conducted in 1999 to determine the status and trends in soil fertility management and associated soil conditions in Bhutan in the face socio-economic development of the last four decades. While the traditional SFM systems based on the use of animal manures still dominate, the ability to maintain and sustain these indigenous systems is being undermined by socio-economic factors. Households have been increasingly depending on fertilizer, especially urea, to increase soil fertility and maintain crop yields, and this trend is predicted to continue. Generally, soil nutrient status is poor. The major concerns are a low pH and nitrogen, phosphate status and imbalanced base nutrition. Since sustainable development is a key government development objective, the survey results were examined to determine the sustainability of existing SFM practices and soil use for crop production. In most situations sustainability is being maintained, but the assessment of SFM and crop production questions sustainability in some areas. Lack of sustainability is a concern on both wetland and dryland soils and among households identified as being less able to manage soil fertility. This paper has identified implications for policy, research and extension.

Introduction

Farming is fundamental to the Bhutanese economy. Some 80% of households depend on agriculture for their livelihood and the share of agriculture to GDP is 37%. Characteristically, farming households are small with a mean farm size of less than a hectare. Wetland (irrigated paddy fields) is preferred and rice is cultivated up to 2,600 masl. Winter cropping of wetland is restricted by low winter temperatures at higher altitudes and lack of irrigation at lower altitudes. Winter cropping is largest at middle altitudes. While only a small proportion is covered here, the double-cropped area is increasing. Maize is the predominant crop on dryland and at higher altitude (above 2,500 masl) wheat and/or buckwheat are the main staples. Although subsistence cropping predominates, mandarin oranges at lower altitudes and apples at higher altitudes are the major cash crops, making an important contribution to GDP. Other important cash crops are potato, cardamom, ginger and chili.

As in any other farming system, soil fertility is fundamental to the productivity and sustainability of farming in Bhutan. Traditionally, soil fertility management (SFM) has been based predominantly on the use of animal manures through either tethering of animals in fields or the use of farmyard-manure (FYM). The traditional labour intensive SFM systems are based on the integrated use of the forest as a source of fodder and leaf litter, livestock for dung, and crops as supply of crop residues. The use of chemical fertilizers has increased substantially parallel to the socio-economic development of the past 40 years. Absolute levels of chemical fertilizer use are low compared to a global level, but households are increasingly relying on these fertilizers.

The objective of this paper is to provide an overview of the status, trends and sustainability of soil fertility management and associated soil conditions in Bhutan against the social and economic transformation. Following a brief description of

the data sources, three main issues are examined namely, trends in SFM practices, soil fertility status and its sustainability. The paper concludes by identifying the implications for policy, research and extension with respect to soil fertility and its management in Bhutan.

Two principal sources were used for this survey: a national Soil Fertility Management (SFM) survey of 1999/2000 and a Watershed Farmyard Manure (FYM) survey of 1998/1999.

Soil Fertility Management (SFM) Survey

A total of 32 villages were selected as representative of farming systems across Bhutan. It used qualitative data collection methods (example PRA and focus group discussion) at the village level to identify major SFM issues and trends in the villages. Information provided by household interviews in a random sample of 12 households per village formed a quantitative data on household SFM practices, resource and perceived trends in yields and soil fertility. For a standard nutrient descriptors, soil samples from a random selection of (380) fields were analyzed.

Farmyard Manure (FYM) Survey

This survey was conducted amongst 23 households in a mid-altitude watershed over one cropping year 1998/1999. Household interviews were used to characterize each household for socio-economic status, resource base and SFM profile. All fields cultivated by the sample households were monitored for a cropping year to determine rates of nutrient application from tethering, FYM and fertilizer application by direct measurement and nutrient analysis.

ISSUES

Soil Fertility Management (SFM) Practices
The trend in the use of the major SFM practices is summarized in Table 1. The increasing use of fertilizers is the most important change. Although only 41% of households

have used fertilizers, the trend is strongly positive amongst households that have used fertilizers, and of these, 66% of households have increased the fertilizers use.

Table 1: Percent of households reporting change in use of tethering, FYM and fertilizers as an SFM practice

SFM Practice	Change in SFM Practice			SFM not used
	Increased	Same	Decreased	
Tethering	14	37	13	37
FYM Use	27	41	15	17
Fertilizers	27	11	3	59

`Source: SFM Survey. 379 household respondents`

A complex of interrelated factors influence the changing pattern of SFM practices in Table 1 but three major factors are identified: fertilizer availability and effectiveness, livestock numbers and management system and household labour availability.

Fertilizers Availability and Effectiveness
Fertilizers have only been available in Bhutan since the early 1960s and their use has been an important part of government agricultural development strategy to increase yields and production. Increased use of fertilizers reflects: 1) their increased availability as road access and distribution systems have improved; 2) effective promotion of their use through agricultural extension programmes; and 3) their effectiveness, providing substantial and cost effective yield increases.

Currently fertilizer prices are subsidized through indirect government support to the national marketing and distribution system.

Livestock Numbers and Management Systems
The supply of animal manures for either FYM or tethering use is dependent on the number of livestock kept and their management system. Data indicates that livestock numbers

are declining. Review of livestock population and composition over the years indicate significant decrease in total livestock numbers and an increase in the number of cross breed livestock at the expense of a decrease in the number of local breed between 1986 and 1996 (MoA, 1999). This trend is complemented by farmers moving from extensive (grazing) through semi-extensive (tethering) to intensive (stall feeding) systems, particularly associated with adoption of crossbreds. Although declining livestock numbers reduce the supply of manure, recovery of dung is greater in the more intensive systems.

Household Labour Availability

Declining availability of household labour is an established trend in Bhutan. In the SFM Survey, 48% of households reported a decline in household labour availability in the last 10-15 years. A contemporary survey in the west-central region confirms this finding, and 50% of 300 respondent households report a decline in household labour availability (Yeshey, 2001). The three reasons reported for labour decline are household members leaving for marriage (30%), government employment (26% of households), and schooling (24%).

Declining labour availability means that the effectiveness of labour use is an overriding factor determining household SFM strategies. Use of FYM is labour intensive and, in the face of declining household labour, households will move to more intensive livestock management systems (ultimately stall feeding) that reduce the labour required (traditionally children) for shepherding. Fertilizer use is an extension of this labour saving strategy; substituting cash for labour in providing plant nutrients.
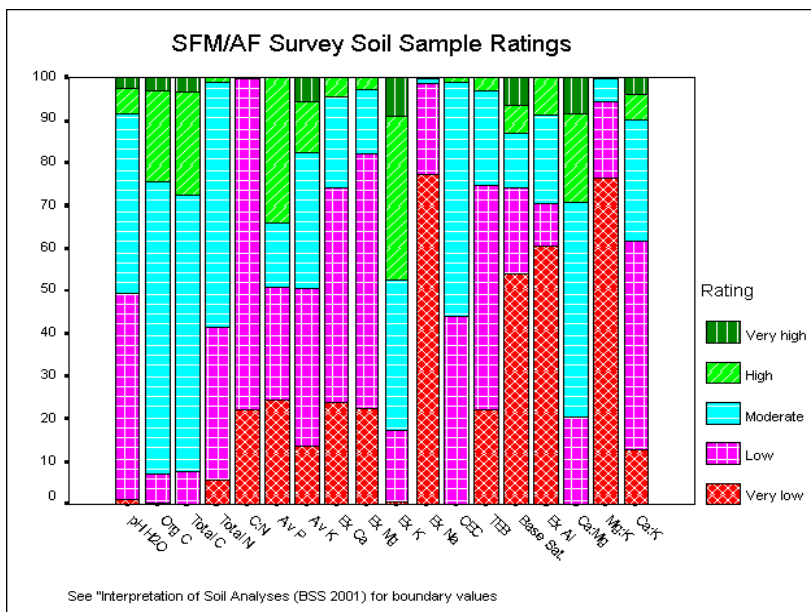
Soil Fertility Status

Soil fertility status is assessed in two ways to provide a broader view. The first is based on the results of the analyses of the soil samples from the SFM Survey, and the second is

based on the household perceptions of yield and soil fertility changes in the last 10-15 years.

Soil Analytical Results
Bhutan is characterized by considerable diversity in agricultural soils. Climatic zones range from the subtropics from 150 masl with high annual rainfall (ca 5500 mm) in the south to cold temperate with low rainfall (400 mm) in the north. Geology is dominated in the north by granitic gneiss and in the south by phyllite schist. This diversity means that even simple stratification of the soil analysis results by soil type and agro-ecozone is lengthy and beyond the scope of this paper. Although any summary of soil nutrient status runs the risk of oversimplification, the results of key soil variables for 376 samples taken from the SFM Survey are summarized in Figure 1 to provide an overview of the results and identify the major features.

Figure 1: Soil nutrient status-rating chart for SFM Survey samples

Figure 1 gives the proportion of the samples that fall into five rating classes for each soil descriptor. The rating class boundaries are derived from international sources and standards and classes are designated very low to very high. Any soil variable in which the proportion of samples classified as low or very low exceeds 40% is considered to indicate a potential soil fertility problem.

The main features of the results given in Figure 1 are:

- Although nearly half of all samples had low or very low pH (i.e. pH <5.5), only 15% of samples had exchangeable aluminium levels classified as high or very high. Except for some lowland subtropical soils, aluminium toxity is of limited concern.

- Total and organic carbon levels are generally adequate although total N levels were low or very low (<0.2%) in 40% of samples. As result of the low total N levels, C:N ratios are favourable (i.e. low or very low [<19]).

- For available P (Bray) and K, 50% of the samples are rated low or very low (<5ppm P and <40ppm K). Of these, low available P is of greatest concern as soil parent materials are generally K rich and this is reflected in predominantly moderate to high levels of exchangeable K.

- The major area of concern is base nutrition and particularly the imbalance between exchangeable bases. Base saturation and total exchangeable base levels are low or very low (>70% of samples). The low to very low exchangeable Ca and Mg levels (more than 70% of samples) as compared to predominantly moderate to high levels of exchangeable K are reflected by unfavourable Mg:K and Ca:K ratios.

Trends in SFM practices are likely to exacerbate these deficiencies. Decreasing use of FYM reduces the additions of P

and Mg and these nutrients are not usually added by the fertilizers used. In addition, the predominant use of urea is likely to exacerbate problems of low pH.

Household Perceptions
An average of 21% and 22% of households reported increased soil fertility of wetland and dryland respectively in the last 10-15 years. In contrast, for wetland 35%, and for dryland 39% of households reported SF as having declined. Household perception of changes in the soil fertility status of their wetland and dryland in the last 10-15 years is illustrated in Figure 2. This perception differs significantly between households depending on their SFM ability (p=0.009). In the case of wetland, 49% of poor SFM ability households reported a decline compared to 27% for good SFM ability households. Comparable figures for dryland are 55% and 31%.

Figure 2: % of households reporting a decline in soil fertility of their wetland and dryland by household SFM ability
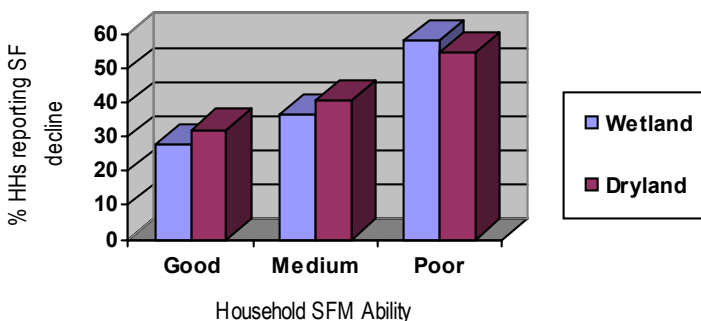
The main indicator used by the majority of households to assess soil fertility is crop yield; other factors such as soil conditions (e.g. colour, tilth and texture) and erosion hazard, although considered, are secondary. The association between soil fertility and yield is confirmed by the survey finding that, on average, 39% of households report a decline in the yield of

their main staple (Table 1). The trend in yield decline is greatest in households with wheat and buckwheat as their main staple; these are predominantly households living at higher altitudes.

Table1: Percent of households reporting specific change in yield of their main staple crop in the last 10-15 years

Yield change in last 10-15 years	Staple Crop				
	Rice	Wheat	Maize	Buckwheat	All Staples
Increase	21	25	33	36	27
Same	43	13	32	9	35
Decrease	36	63	35	55	39
Household count	183	24	140	22	374

Source: SFM Survey

The association between crop yield and soil fertility is reinforced by the reasons given by respondent households for staple crop yield increases or decrease (Table 3). The main reasons given for yield increase are the use of fertilizers and/or more FYM. Conversely, soil fertility decline dominates the reasons given for yield decrease. In the Bhutanese context an important feature of these results is that 'soil fertility decline' was reported as a reason for yield decrease by three times as many households as those reporting yield decrease due to damage by wild animals. Hitherto, crop damage by wild animals has been widely reported and regarded as the most important problem facing farming households.

Table 1 Reasons reported by households for yield increase or decrease in the household's main staple crop

Reasons reported by more than 5% of households for:	% of households
Yield increase	
Use of chemical fertilizers	32

Use of higher yielding crop varieties	27
Application of chemical fertilizers with FYM	24
Application of FYM	22
Reporting households	99
Yield decrease	
Soil fertility decline	46
Damage by wild animals	16
Use of less FYM and compost	14
Pests and diseases	12
Water shortage	9
Better crop management	8
Reporting households	142

`Source: SFM Survey`

While accepting that crop yields reflects other influences particularly weather, water availability and crop management, these results illustrate that soil fertility is declining in a significant proportion of agricultural land. They also demonstrate that soil fertility and its maintenance is an important feature affecting farming in Bhutan and that it is stratified. Households identified as being less able to manage soil fertility and those at higher altitudes depending dryland staple crops appear at most risk.

Sustainability

Sustainability is a complex issue and any discussion needs to be clear as to what defines sustainability. Here the definition that "a system is sustainable over a defined period if outputs do not decrease when inputs are not increased" (Monteith, 1990).

The evidence presented above of declining soil fertility and crop yields and increasing use of fertilizers suggests that the lack of sustainability of SFM systems in Bhutan is a major concern. About 40% of households are reporting decline in soil fertility and staple crop yields. Soil fertility decline is reported as a major reason for yield decline and the main

strategy for maintaining or increasing yield is reported as the use of chemical fertilizers (Table 3).

A complex of socio-economic factors, probably most importantly a decrease in household labour availability and lack of profitability of farming underlie the decline in yield and soil fertility and in particularly undermine the sustainability of the traditional SFM systems based on animal manures. It is not possible to present and discuss these socioeconomic factors in detail in this paper. The evidence shows that a major factor involved in the (un)sustainability of SFM systems is the increased use of chemical fertilizers and for this reason this paper concentrates on this aspect of the problem.

Chemical Fertilizer Use Patterns

Urea is the main fertilizer used in Bhutan. Of the 2,016 metric tonnes of chemical fertilizers used in 1999, 56% was urea. The ratio of N:P:K in fertilizer sold in the three years to 1999 was 5.7: 1.3: 1 and indicates a serious imbalance in nutrient use. Survey results confirm the dominance of urea and show that, with the exception of potato, most households use urea only (Table 4). The use of compound and phosphatic fertilizers in potatoes is related to potato's role as a cash crop. There is a large economic response to single super phosphate (SSP) in potato and its use has been strongly promoted by the extension services. On other crops farmers mostly use urea.

Table 2: Mean farmer estimated rates of fertilizer applied (kg ha⁻¹) for urea, suphala and single superphosphate by crop

Fertilizer applied	Crop (Fertilizer application rate ±sem where applied with [respondent] number)			
	Rice	Wheat	Maize	Potato
Urea (0:46:0)	95±9 [80]	104±17 [18]	164±15 [43]	213±40 [34]

Suphala (15:15:15)	64±17 [9]	133±33 [6]		217±44 [22]
Single Superphosphate (0:16:0)	72±43 [4]	115±28 [6]		247±37 [24]

Source: SFM Survey

The extent to which households are dependent on fertilizer for yield is shown in Table 5. These substantial yield increases using relatively low rates of fertilizer use (Table 4) illustrate why fertilizer use is attractive to farmers.

Separate estimates suggest that in two of the main rice producing valleys as much as 30% of the current production of rice is due to the application of urea (SSF & PNMP unpublished data).

Table 5: Mean farmer estimated yields with and without fertilizers applied and percentage yield increases resulting from fertilizer use by crop

Crop	Rice	Wheat	Maize	Potato
Yield (kg ha^{-1}) with fertilizers	5,590 ±280	2,870 ±880	4,408 ±470	12,450 ±2,000
Yield (kg ha^{-1}) without fertilizers	3,970 ±210	1,790 ±590	2,662 ±300	7,100 ±1,300
Yield change (%) with fertilizers based on farmers' estimated yields	51	70	66	88
Farmers' estimated yield change (%) if unable to recall actual yield change	37	38		38
Overall yield change (%) mean of previous two rows	59	64	76	60
Respondents	71	17	42	25

Source: SFM Survey

The predominant use of urea has important implications for the sustainability of soil use and this is illustrated below with partial nutrient budgets from a wetland and dryland soils.

Wetland Soils

Partial nutrient budget for nitrogen, phosphorus and calcium from 102 fields growing rice in the FYM survey are illustrated in Figure 3, Figure 4 and Figure 5.

In the figures, fields have been sorted by increasing amount of the nutrient applied from three sources, FYM, tethering and fertilizers[1]. The lowest Y-axis gridline in the figures is fixed at the amount of the nutrient removed by the estimated mean yield of a rice crop amongst the surveyed households. The amount of nutrient removed by the estimated mean yield rice crop is about 46 kg N ha^{-1}; 13 kg P ha^{-1}; 69 kg K ha^{-1}; and 18 kg Ca ha^{-1}. The other Y-axis gridlines are multiples of this nutrient removal.

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[1] Nutrient recovery assumed as 80% from organic sources and 50% from inorganic fertilizers.
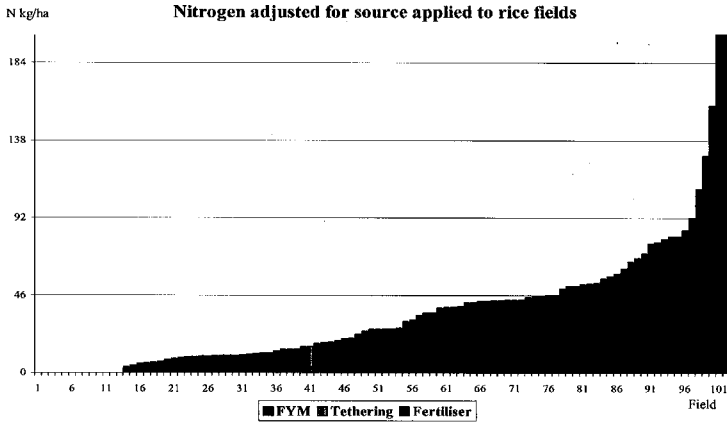
N kg/ha   **Nitrogen adjusted for source applied to rice fields**

Figure 3   **Partial nitrogen budget for rice fields in the Lingmutey Chhu watershed 1998-99**

P kg/ha   **Phosphorus adjusted for source applied to rice fields**
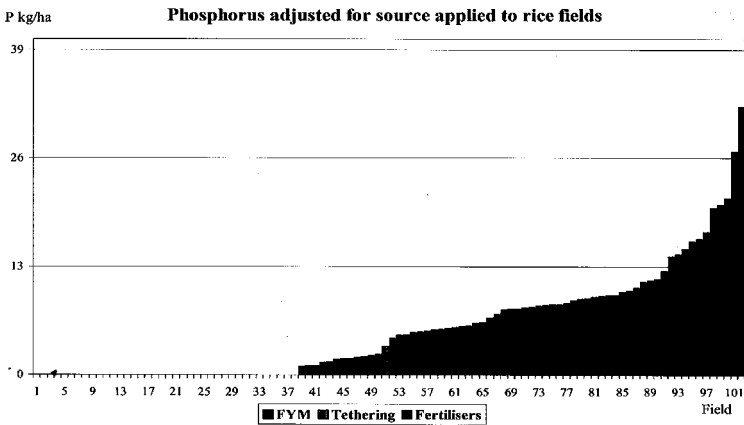
Figure 4   **Partial phosphorus budget for rice fields in the Lingmutey Chhu watershed 1998-99**
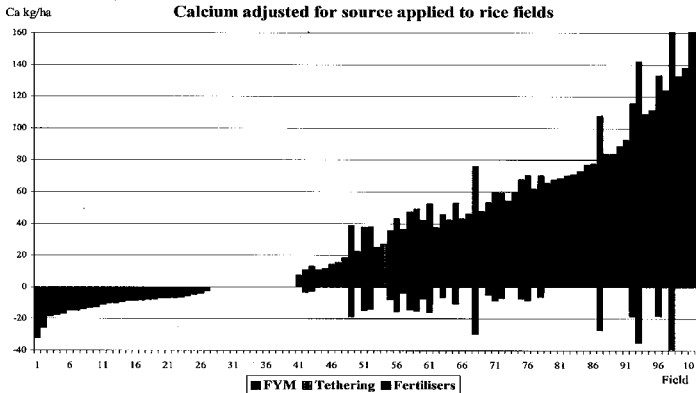
Figure 5   **Partial calcium budget for rice fields in the Lingmutey Chhu watershed 1998-99**

The main results and issues that emerge from the partial budgets results are;

- More than 50% of fields are receiving less N and P than is removed by a rice crop of estimated mean yield. This proportion is 78% for N and 92% for P.
- The proportion of fields not receiving N, P and Ca from nutrient management is between 20% and 40%; the situation is worst for P and Ca because these nutrients are not being supplied in fertilizers.
- As a result of the Ca needed to neutralize the urea applied as fertilizer, an effective negative application of Ca is occurring in 29% of rice fields. Thus 40% of the fields are effectively receiving no, or a negative application of, Ca.

Continuation of this management regime will mean that it will be difficult to increase rice yields without the risk of depleting soil nutrient stocks, particularly of P and Ca. P and Ca are of greatest concern; FYM derived from cattle is a poor source of

P and Ca is not being provided in fertilizers and liming is not an established practice in the area.

Dryland Soils

Comparable partial budget information is not available for dryland soils. However, data from the SFM Survey for dryland fields (Table 6) relating household perceptions of SF changes to whether chemical fertilizers are applied to those fields demonstrate a significant ($P<0.001$) association between perceived SF change and fertilizer use. Where SF is perceived as having remained the same or has decreased, fertilizer is not used on most fields (71% and 89%). Where SF is perceived to have increased, fertilizers are used on most fields (58%).

As the rate of urea applied is higher on maize crops than rice crops (Table 2) it is assumed that the partial nutrient budgets for dryland fields would be comparable to those illustrated here for wetland. FYM survey results show that FYM application rates to rice (7,800 ±700 kg FYM ha^{-1}) and maize (8,100 ±1,700 kg FYM ha^{-1}) are similar.

Table 5 : Perceived changes in soil fertility on dryland versus fertilizer use (% of fields)

Fertilizers used on field	Perceived soil fertility change		
	Increased	Same	Decreased
No	42	71	89
Yes	58	29	11
Respondents	55	62	71

Source: SFM Survey

IMPLICATIONS

This paper identifies implications of soil fertility management in Bhutan at a policy, research and extension level.

Policy

1. Improving SFM will depend substantially on improvements to the productivity and profitability of the farming system.

The more productive and profitable farming is the greater the incentive to invest. In particular, improvements needed are those that are compatible with improved FYM and fertilizer management and use and those that increase returns to labour. Here improvements in infrastructure and markets are important, especially if these are likely to stimulate intensive livestock production.

2. Given the large and negative impacts of imbalanced use it is important that fertilizer prices are not subsidized and so do not undervalue the traditional and more soil friendly methods based on FYM use. At the same time further liberalization of fertilizer distribution systems is needed to provide widespread and improved access to this important SFM input.

Research
3. The most important research implication arising is the issue of sustainable soil fertility management on both wetland and dryland.

Nutrient budgets for rice in the FYM survey indicate that P and Ca are priorities but, given the low exchangeable Mg against rich K soils, poor and imbalanced base nutrition identified in the soil sample results, Mg nutrition also needs consideration.

4. More information is needed for maize production on dryland. Here use of urea is widespread but negative effects may be being offset by the general higher rates of FYM application on maize than on rice.

5. There is a need to examine the importance of poor and imbalanced base nutrition in improving productivity of the main high value crops of apples and mandarin. These crops are major contributors to agricultural domestic product and improved soil fertility and so increased use of fertilizers need to be an important component of strategies aimed at increasing production and productivity.

6. Addressing the other important but general constraints with respect to FYM use requires farmer relevant options to increase the supply of FYM and to reduce its labour requirements. In this respect, on-farm fodder crops are the priority.

Extension

7. The priority for extension is to work with farmers to address imbalanced fertilizer use. Fertilizer use is the single most important change in SFM that has occurred in the last 10-15 years and farmers lack the understanding of simple principles of crop nutrition to be able to make informed decisions on fertilizer use.

8. The other priority for extension is to promote on-farm fodder crops to increase the supply of FYM and to reduce its labour requirements by facilitating more intensive livestock management systems.

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