Available online at www.sciencedirect.com
SCIENCE DIRECT®
Agriculture, Ecosystems and Environment 103 (2004) 191–206
Agriculture Ecosystems & Environment
www.elsevier.com/locate/agee

Perceptions and assessment of soil fertility by farmers in the mid-hills of Nepal

Arnaud Desbiez[a,1], Robin Matthews[a,*], Bhaba Tripathi[b], Jim Ellis-Jones[c]

[a] Institute of Water and Environment, Cranfield University, Silsoe, Bedfordshire MK45 4DT, UK
[b] Agricultural Research Station Lumle, PO Box 1, Pokhara, Nepal
[c] Silsoe Research Institute, Wrest Park, Silsoe, Bedford MK45 4HS, UK

Received 11 September 2002; received in revised form 22 July 2003; accepted 7 October 2003

Abstract

To design more appropriate research and to facilitate communication with farmers, researchers need to understand farmers' knowledge, perceptions and assessments of soil fertility. To address this issue for the mid-hills of western Nepal, semi-structured interviews were conducted in 68 households to gain insight into soil fertility management practices, local methods used to assess the fertility status of a field, and perceived trends in soil fertility. Thirty-three farmers were then asked to identify fertile and infertile fields. Characteristics of these fields in terms of the indicators mentioned in the interviews were recorded, and soil samples were taken for chemical analysis in a laboratory. Data were stratified according to altitude and type of field, *khet* (irrigated) and *bari* (rainfed).

A total of 62 indicators was found to be used by farmers to evaluate and monitor soil fertility, which were classified into five categories: those relating to soil characteristics, crop performance, agricultural management, environmental factors, and biology. There was good agreement between farmers' assessment of the soil fertility status of a field and a number of these indicators, particularly soil colour and weed abundance, which were examined in more detail. The soil chemical analysis also corresponded well with farmers assessment of soil fertility.

Farmers' perceptions of soil fertility were found to be more 'holistic' than those of researchers, as they included factors they felt influenced the soils and crop growth in their fields. The term 'field fitness' is proposed as it conveys farmers' perceptions more accurately than 'soil fertility' alone.

Keywords: Soil fertility; Indicators; Farmer perceptions; Soil colour; Weeds

1. Introduction

Farming in the mid-hills of Nepal is characterised by a close relationship between crop production, livestock and forestry, with trees and crops providing fodder and bedding materials for livestock, which in turn provide draft power and manure. Soil fertility is largely maintained by the application of compost and manure, but in recent years a decline in soil fertility has been reported (e.g. Shrestha et al., 2000).

There has been considerable research in Nepal on soil fertility enhancement and soil and water conservation techniques over the years (e.g. Keatinge et al., 1999; Acharya et al., 2000). In addition, a significant body of relevant indigenous knowledge has been documented (e.g. Thapa et al., 1997). Even though

* Corresponding author. Tel.: +44-1525-863008; fax: +44-1525-863344.
E-mail address: r.b.matthews@cranfield.ac.uk (R. Matthews).
[1] Present address: Durrell Institute of Conservation and Ecology, University of Kent, Canterbury, Kent CT2 7NZ, UK.

0167-8809/$ – see front matter
doi:10.1016/j.agee.2003.10.003

the decline in soil fertility is a major concern for most farmers (Turton et al., 1995), their adoption of improved techniques has been limited (e.g. Shrestha et al., 2000). Although much of this is due to poor dissemination pathways resulting from inadequacies in the agricultural extension system, an important factor may be the different ways that farmers, extension workers and researchers all perceive and assess soil fertility, leading to differences in the problems perceived and solutions required.

Until recently, farmers' knowledge of soil fertility has been largely ignored by soil researchers, but with increasing use of participatory research approaches, it is becoming clear that farmers have a well-developed ability to perceive differences in the level of fertility between and within fields on their farms. The soil classification systems of the hill farmers of Nepal have already been documented (Tamang, 1991, 1992; Turton et al., 1995), and these studies have shown that farmers use a range of criteria, including economic and ethnic influences, to categorise their soils, but that soil colour and texture are the dominant criteria. They also see the actual fertility of a soil at any time as a function not only of these longer-term soil properties, but also of the current and past management regime. As such, they assess the fertility of the soil using a range of indicators which they can actually see or feel, including crop yields, soil depth, drainage, moisture, manure requirements, water source, slope, and weed abundance.

Compared to this 'holistic' perception, researchers generally take a more reductionist approach to soil fertility, often accounting only for the soil's nutrient status or physical characteristics. There is a strong need to compare the indicators used by farmers with those used by researchers. In the work reported in this paper, we build on the findings of these previous descriptions by studying farmers' perceptions and assessment of soil fertility in more detail, and comparing them with the criteria of soil fertility used by researchers.

2. Materials and methods

2.1. Site description

The study was conducted from July to September 2001 in five wards of the Pakuwa Village Development Committee (VDC) in the Parbat district of western Nepal. Two agroecological zones were defined—lower Pakuwa, consisting of wards 5–7, with an altitude range of 850–1100 m, and upper Pakuwa, consisting of wards 8 and 9, where the altitude ranged from 1100 to 1500 m. Slopes in upper Pakuwa were generally steeper, and the climate more extreme. However, the most important distinguishing feature results from the construction of a canal in the early 1970s which irrigates most of lower Pakuwa. Both zones are predominantly inhabited by people of the Brahmin and Chhetri ethnic groups, and almost all of the households are engaged in agriculture to a lesser or greater degree. All the arable land is under level terraces hill slope cultivation. Average annual rainfall in the region is 3180 mm.

The farming system consists of: (a) bunded lowland irrigated or partially irrigated levelled land called *khet*, (b) unbunded upland rainfed levelled or sloping terraces called *bari*, (c) kitchen gardens, and (d) pasture land. Most land is either privately owned or rented, although pasture land is sometimes owned by the community. Surrounding forest is owned and managed by community forestry groups. The main crops include successive rotations of wheat (*Triticum aestivum* L.), potatoes (*Solanum tuberosum* L.), spring maize (*Zea mays* L.), and rice (*Oryza sativa* L.) in the *khet* land, and a maize/millet (*Eleucine coracana* (L.) Gaertn.) relay system in the *bari*. Livestock is generally stall-fed except for goats. Population densities are higher than 700 people km^{-2} of arable land (World Bank, 2001).

2.2. Household interviews

Information on farmers' perceptions of soil fertility and the indicators they use to assess the fertility status of their fields was gathered through individual semi-structured interviews which took place in the interviewee's house. Conversations, which were translated by an interpreter, were guided towards selected topics while remaining flexible enough to include any other topics of interest to the farmer. Topics covered included soil fertility management practices, local methods used to assess the fertility status of a field, and perceived trends in soil fertility. Information was recorded in a notebook, and a check list kept to make sure all topics were covered. If necessary, households were visited several times to confirm and re-check information or to speak with other members of the household. Special care was taken to ensure that the most experienced member of the household was interviewed. These most experienced members were identified for each household by two of the village elders in upper Pakuwa and two in lower Pakuwa.

Only fields owned and worked by farmers were discussed. The few fields that were rented out to other farmers, or fields that were being rented by the interviewee, were excluded from the discussions to minimise errors due to a possible lack of knowledge regarding the management of these fields. Similarly, although farmers distinguish two layers of soils—the top layer reached by the plough (∼20 cm depth) and the layer underneath it—during the interviews they discussed only the top layer; we have, therefore, restricted our analysis to this top layer.

2.3. Field characteristics

From those interviewed, a subset of 33 farmers were selected at random and asked to indicate their most fertile field and their most infertile field. Each of these fields and its surrounding environment was then characterised according to its distance from the household, its size, terrace height, tree shade, stoniness, aspect of crops, and hardness of the soil felt when sampling (see the next section).

The presence, abundance, and cover of agricultural weed species were also recorded in three randomly selected 1 m^2 quadrats in each field. Samples of the weeds were collected in paper envelopes, dried and pressed between sheets of newspaper, and identified using the herbarium at the Agronomy Division of the Nepal Agricultural Research Centre (NARC) at Khumaltar, Kathmandu.

Information on the soil characteristics and management of the field were obtained from discussions with the farmer on the fertility status, history, or particular problems of the field, with particular emphasis on those indicators mentioned by the farmer during the interview.

3. Soil sampling and analysis

Soil samples were also collected from each of the selected fields described above. Of these, 34 samples (16 from lower Pakuwa and 18 from upper Pakuwa) were taken from *khet* fields between mid-August and mid-September, when rice had been growing for at least a month. Similarly, 32 samples (16 from lower Pakuwa and 16 from upper Pakuwa) were taken from *bari* fields between the end of July and early August, corresponding to the time when the maize was ripe and millet at least 1 month old. Due to their different nutrient management (i.e. dumping of kitchen waste), *bari* fields used as kitchen gardens during the winter season were not included, as they were small and tended to receive higher levels of organic waste.

Each soil sample was made up of 10–20 sub-samples randomly collected from the 0 to 20 cm deep plough layer using an auger, at least 1 m from the terrace edges, although in the case of some very narrow fields, this distance had to be reduced to 0.5 m. The sub-samples were spread and mixed together on a large clean plastic sheet, any clods thoroughly broken, and vegetative material and stones removed to create a uniform mix. The mix was then divided into four equal parts from which two diagonal parts were retained, the other two parts being returned to the field. Quartering continued until the weight of the composite sample was approximately 1 kg. Samples were then placed in a numbered plastic bag, air-dried for 3–6 weeks, and analysed at the Agricultural Research Station Lumle (ARSL) soil laboratory.

For this, the air-dried samples were crushed and passed though a 2 mm sieve. Soil pH was determined by a pH meter after extraction from a soil:water ratio of 1:2.5. Organic C was determined using the Walkley and Black dichromate method, and total N using the standard micro-digestion method (Kjeldahl) with colorimetric determination by spectrophotometer. For available P determination, the Bray and Kurtz method (0.03 M NH_4F/0.1 M HCl extraction) was used. Exchangeable K was estimated by 1 M ammonium acetate extraction followed by flame photometric determination.

3.1. Soil colour

Soil colour was quantified with a Munsell chart (Munsell Color Services, New Windsor, NY), which uses *hue*, *value* and *chroma* indices to describe colours. *Hue* identifies the colour's approximate place in the rainbow (how red or yellow or blue it is), *value* identifies how light or dark it is, with values near 0 being white, and *chroma* identifies how much colour there is, from very faded to very intense. The lower the value and chroma, the darker the soil.

3.2. Weed growth

General weed cover of a field was assessed using an index ranking from 1 (very low weed cover) to 6 (total weed cover). Additionally, average height of weeds was estimated using an index from 1 to 5:

Index	Canopy height (cm)
1	<10
2	10–20
3	20–30
4	30–50
5	>50

For *Ageratum conyzoides* L., the Domin scale (Shimwell, 1971) was used to analyse abundance and cover on a scale from 1 to 10.

4. Results

4.1. Household characteristics

The key characteristics of the sample households, including the gender and numbers of years' working experience in the fields of the interviewees are summarised in Table 1. In general, households in upper Pakuwa owned more land overall (*khet* + *bari*) than households in lower Pakuwa. However, in upper Pakuwa, all the *khet* land depended on partial irrigation which allowed a maximum of two crops per year, whereas in lower Pakuwa the *khet* was fully irrigated by canal water, enabling not only three crops per year to be grown, but also giving higher and more reliable crop yields. The crops grown, and their management, varied greatly between fields from households in both areas.

The management of *bari* fields, on the other hand, was similar between all households surveyed. This consisted of three ploughings—the first in January/February to break up the soil, the second in March to remove the weeds, and the third in April before planting. Either maize and millet were planted, although these were sometimes intercropped with beans (*Phaseolus vulgaris* L.), peas (*Pisum sativum* L.) or arum (*Arum indicum* L.).

Table 1
Characteristics of the households sampled

	Upper Pakuwa	Lower Pakuwa	Total
Number of households interviewed	28	40	68
Household ethnic group			
Brahmin	18	29	47
Chhetri	5	9	14
Other	5	2	7
Number of men interviewed	22	25	47
Number of women interviewed	23	27	50
Average experience of interviewee (years)	20.3	23.5	22.2
Average *bari* size holding (*ropani*)	4.5	2	3.05
Average *khet* size holding (*ropani*)	10.15	7.1	8.35
Mean number of buffalo owned	1.7	1.5	1.6
Mean number of oxen or cows owned	1.3	1	1.13
Mean number of goat or sheep owned	2.95	1.4	2

Note: 1 *ropani* = 0.05 ha.

Farmers in upper Pakuwa owned more sheep and goats and slightly more cattle than their counterparts in lower Pakuwa, but as they also owned more land, there was little difference in animal manure availability per unit area.

4.2. Farmers' soil classification

Although they did describe soils as stony, sandy and heavy, farmers were found to classify their soils more according to their colour rather then texture. The main properties of these different soils were stated by farmers to be the soil fertility, manure requirement, erosivity, and moisture retention (Table 2).

In *khet* fields, both white (*seto mato*) and black (*kalo mato*) soils are highly valued. The term white soil is somewhat misleading—these soils are, in fact, very dark in colour (as dark or sometimes even darker than black soils), but are called white because of small shiny mica grains that become apparent when the soil is irrigated. This gives some fields a shiny grey appearance as they reflect light. Generally, in *bari* fields, black soils are the most highly valued soils and red soils (*rato mato*) somewhat less so.

Table 2
Farmers' classifications of soil types and their perceived properties in *khet* and *bari* fields at Pakuwa

Soil types	Occurrence	Colour	Fertility	Manure demand	Erosivity	Moisture retention
Kalo mato	Upland *bari* and *khet*; lowland *bari* and *khet*	Black	High	Low	Medium	High
Seto mato	Upland *khet*; lowland *khet*	White	High	Low	Medium/high	Medium/high
Khairo mato	Upland *bari* and *khet*; lowland *bari* and *khet*	Brown	Medium	Medium	Medium	Medium
Pahelo mato	Upland *khet*; lowland *bari* and *khet*	Yellow	Medium/low	High	High	Medium/low
Rato mato	Upland *bari* and *khet*; lowland *bari* and *khet*	Red	Low	High	Medium/high	Low

4.3. Farmer indicators of soil fertility

During the interviews, 62 indicators were mentioned by farmers as tools they used in assessing the fertility of their soils (Table 3). Usually, fields were characterised as either fertile or infertile, with indicators described dichotomously as either good or bad, or high or low. Exceptions to this were soil colour, soil texture, and water quality, where descriptive terms and a subtle gradient were used.

We classified farmers' indicators according to the following categories:

- *Soil characteristic indicators*: soil properties which the farmers felt characterised fertile or infertile soils.
- *Agricultural management indicators*: indicators reflecting decisions in soil management.
- *Crop performance indicators*: crop characteristics reflecting soil fertility status.
- *Environmental indicators*: external factors which the farmers felt influenced soil fertility.
- *Biological indicators*: plants (other than crops) or animals whose density or growth reflected soil fertility status.

The principal indicators mentioned by farmers were soil colour (mentioned by 87% of the farmers), crop yield (76%), quantity of FYM applied (75%), water availability (66%), stoniness (57%), difficulty to plough (56%), colour of crop (51%), soil hardness (49%), response to manure (46%), moisture content (37%), crop height and growth rate (35%), water supply (32%), water holding capacity (31%), and shade (28%). The relevance of each indicator was found to vary according to whether the farmer was referring to *khet* or *bari* land. Farmers focused as much on the practice or condition they believed generates or destroys soil fertility as on the properties themselves.

Indicators were further classified according to the time-scale over which they change (see Table 3). Those that change in a few days or within the season, as a result of routine management or due to unpredictable events, were classified as *short term*, while those that change only over several years were classified as *medium term*, while those that are inherent to the site were classified as *long term*. Results show that short-term indicators (44% of the total number) were used more frequently than medium-term indicators (28%), and long-term indicators (28%). Interestingly, the numbers of medium-term and long-term indicators together were more than the number of short-term indicators.

When farmers were asked which characteristics were associated with the fields that they had designated fertile in comparison to infertile, the largest number cited better crop appearance, followed by less stoniness, lower height of terraces below the field, more weeds, and less soil hardness. Other factors included the greater field width, lower height of terraces above the field, larger field size, less distance from the house, easier access, more farm-yard manure applied, and less shading by trees. In general, fertile *khet* fields were closer to the household, larger in size, wider, had smaller terraces above and below the field, had less evidence of landslides surrounding the field, had better crop appearance, and had less stony and more friable soils. Similar characteristics were given for fertile *bari* fields, as well as easier access, higher manure applications, and a higher presence of weeds. Thus, overall there was a strong agreement between the farmers' assessment of fertile and infertile fields and the indicators that they had said in the interviews they used to assess soil fertility. There was, however, considerable variation between individual farmers in the indicators used.

Table 3
Classification of indicators used by farmers in the mid-hills of Nepal to assess soil fertility[a]

Soil characteristics (100%)	Crop performance (97%)	Environmental factors (87%)	Agricultural management (99%)	Biological indicators (32%)
Colour of soil (87%, medium)	Yield/amount of crops (76%, short)	Quality of water source (32%, long)	Quantity of FYM applied (75%, short)	Pest outbreaks (16%, short)
Stoniness (57%, long)	Colour of crop (51%, short)	Shade from trees (28%, medium)	Water availability/irrigation (66%, medium)	Presence of weeds (16%, short)
Hardness to touch (49%, medium)	Crop size (35%, short)	Distance from water source (28%, long)	Difficulty to plough (56%, medium)	Invertebrates beneath the soil (15%, short)
Response to manure (46%, medium)	Growth rate (32%, short)	Distance from house (24%, long)	Quantity of inorganic fertiliser applied (29%, short)	Invertebrates above the soil (13%, short)
Moisture (37%, medium)	Crop suitability (26%, short)	Landslide potential (19%, long)	Number of crops planted (rotations) (21%, medium)	Weed species (10%, short)
Water holding capacity (31%, medium)	Crop height (25%, short)	Size of plot (17%, long)	Quantity of FYM needed (19%, medium)	Weed cover (7%, short)
Soil texture (19%, long)	Disease (10%, short)	Terrace heights (16%, long)	Quantity of chemicals needed (12%, medium)	Weed height (7%, short)
Erosivity (12%, long)	Density of plants (9%, short)	Potential of destruction by monkeys (13%, long)	Quality of ploughing (10%, short)	Rats (4%, short)
Infiltration (12%, medium)	Size of fruit seed (9%, short)	Slope (13%, long)	Number of ploughings (3%, short)	Weed colour (1%, short)
Soil temperature (10%, long)	Crop appearance (7%, short)	Southern exposition (7%, long)		
Topsoil depth (10%, medium)	Crop roots (4%, short)	Water temperature (6%, long)		
Emergence of rocks (7%, medium)	Germination (4%, short)	Altitude (6%, long)		
Heaviness of soil (4%, medium)	Crops wilting early (4%, short)	Position within fields (4%, long)		
Soil compactness (3%, medium)		Roots of trees in field (3%, long)		
Response to chemicals (1%, medium)				
Cracks forming in the sun (1%, short)				

[a] Percentages and time-scale are specified in parenthesis.

It became clear from the discussions that farmers use soil fertility indicators to make soil management decisions and for subsequent monitoring and assessment. However, rather than using just a single indicator to make a decision or assessment, they use at least five, with some even mentioning up to 15. Each indicator is interpreted separately, but their significance is combined when making a decision or assessment. The following table illustrates some examples of how, and which indicators are used by farmers for different questions.

Decision/assessment	Indicators used
What is the current soil fertility?	Soil colour, crop yield, soil hardness, weeds
What potential does this field have?	Quality of water source, stoniness, moisture
Are changes in soil management needed?	Crop colour, crop germination
Is it worth investing in fertiliser or manure?	Water availability, landslide potential, response to manure
Is the soil management strategy in this field working?	
Short term	Crop size, invertebrates beneath the soil
Long term	Difficulty to plough, moisture, weeds
What crop should be grown?	Soil colour, number of crops planted (rotations)
How is the current crop performing?	Growth rate, crop size, density of crops

4.4. Comparison of farmer and researcher perceptions of soil fertility

4.4.1. Soil chemical analysis

The results of the soil chemical analysis of the sampled fields are shown in Table 4. Most soil pH values fell within the ranges of 5.5–4 indicating strongly acidic to extremely acidic conditions corresponding to results from other middle hill areas (Schreier et al., 1994). Nitrogen levels were intermediate in fertile fields and low in infertile fields in both *khet* and *bari* lands. Levels of phosphorus and potassium were intermediate overall with higher values in the fertile fields than in the infertile fields. Values for organic matter were found to be surprisingly low overall.

There was a strong correspondence between the farmers' assessment of soil fertility and the measured soil chemical characteristics. Fields that were described by farmers as fertile were found on average to have significantly higher values of percentage of organic matter, total nitrogen, available phosphorus, and exchangeable potassium, and a higher pH, although this difference was not significant. However, several of these variables are likely to be correlated with one another, and therefore are not independent. Principal component analysis (PCA) provides a way of transforming these possibly correlated variables into a smaller number of uncorrelated variables called principal components, so that number of variables

Table 4
Soil chemical characteristics of farmer designated fertile (F) and infertile (I) *khet* and *bari* fields in lower and upper Pakuwa[a]

	Lower Pakuwa				Upper Pakuwa				$LSD_{0.05}$
	Khet		*Bari*		*Khet*		*Bari*		
	F	I	F	I	F	I	F	I	
%OM	2.07	1.30	3.02	2.76	2.61	1.36	2.91	2.04	0.55
%N	0.199	0.157	0.183	0.145	0.201	0.172	0.216	0.153	0.034
P (ppm)	38.2	25.1	37.5	19.8	36.9	16.2	37.4	15.6	9.08
K (ppm)	89	51	179	90	114	84	204	109	29
pH	4.809	4.489	4.905	4.387	4.458	4.453	4.876	4.261	0.234
n	8	8	8	8	9	9	8	8	

[a] $LSD_{0.05}$ indicates the least significant different at the 5% level of significance for comparisons between fertile/infertile means.

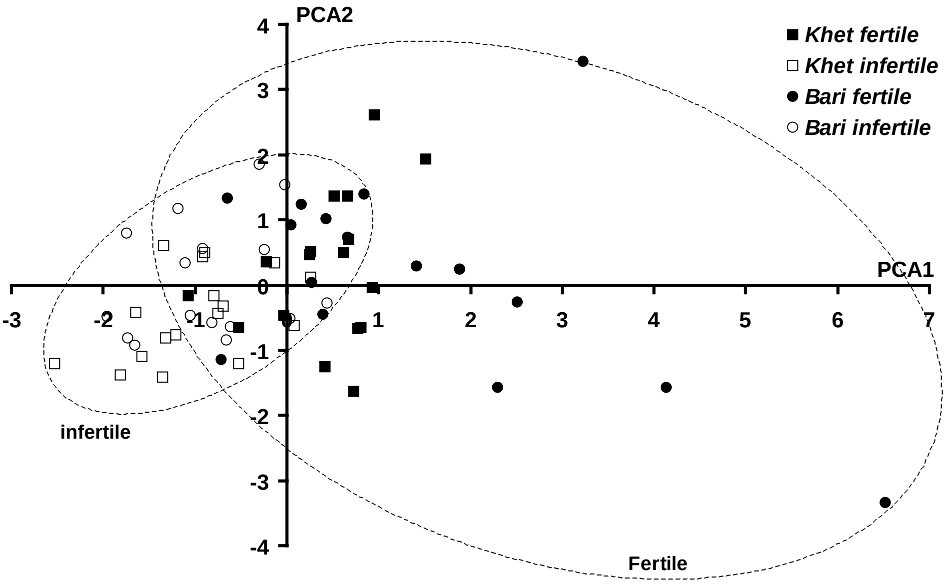

Fig. 1. Score-plot for first two principal components (PCA1 and PCA2) for the soil analysis data. The samples are grouped according to the 'fertile' or 'infertile' classification given to the fields by the farmers. PCA1 and PCA2 were able to explain 69% of the total variation.

of the data set is reduced but most of the original variability in the data is retained. Fig. 1 shows the score-plot from the first two principal components, with the data points grouped according to farmer classification. Although there was some overlap, there is clear separation of the fertile and infertile groups, with much greater variation evident in the fertile group. PCA1 (predominantly pH and K) and PCA2 (predominantly %N and %OM) together were able to explain 69% of the total variation.

Although there were very noticeable social and economic differences between upper and lower Pakuwa (Table 1), there were no statistically significant differences in either *khet* or *bari* between soil properties of fields described as fertile in the upper area and of those described as fertile in the lower area. This was also found for fields described as infertile. These results showed that the agroecological zone did not influence farmers' perception of soil fertility.

4.4.2. Soil colour

As already discussed, the interviews with the farmers showed that soil colour was the most widely used indicator. Generally, the darker soils were considered to be more fertile than the lighter yellow or red ones (Table 5).

The value and chroma of moist infertile and fertile *khet* and *bari* soils are shown in Figs. 2 and 3. As most soils sampled fell within the 10YR colour hue, only these are shown. The few not belonging to the 10YR hue, which suggests a different parent material, tended to be darker fertile soils. Dry soils revealed a similar pattern. It can be seen that the soils classified by the farmer as fertile had a lower value and chroma, indicating that they were darker in colour.

Table 5
Numbers of farmers using specified colour descriptions of their 'fertile' and 'infertile' *khet* and *bari* fields

Colour description	*Khet*		*Bari*	
	Fertile	Infertile	Fertile	Infertile
White	7	1		
Black	7		6	
Light black/white	1			
Light black				1
Mix brown/black	1	1	2	
Brown	1	3	5	3
Mix brown/red		2		
Red		9	2	11
Light yellow/brown				1
Yellow		1	1	
Total	17		16	

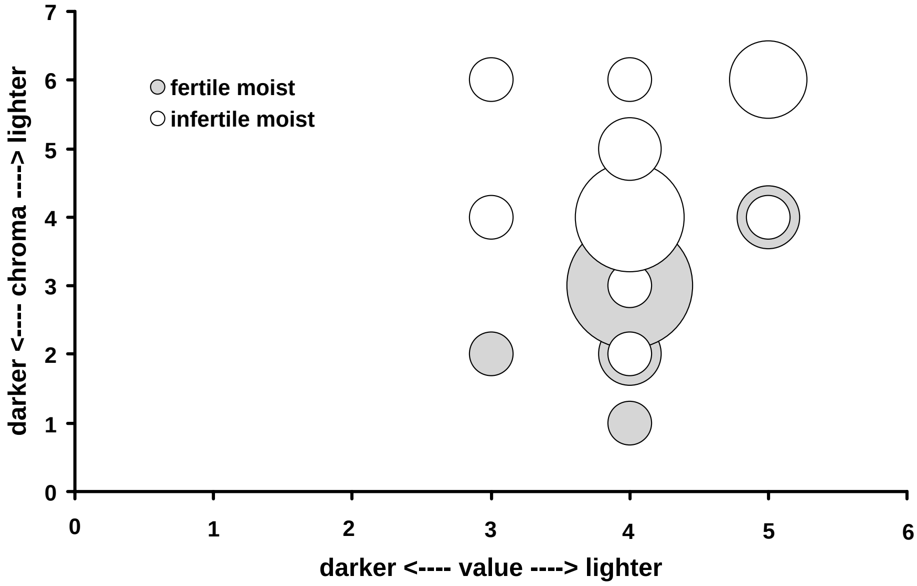

Fig. 2. Comparison of soil colour between fertile and infertile *khet* fields. The size of each bubble is proportional to the number of samples at the corresponding value/chroma combination.

4.4.3. Weeds

Weeds were mentioned spontaneously by only a few farmers (16%) in reference to *bari* fields and even less in reference to *khet* fields. However, when questioned specifically about whether there were differences in the presence of weeds within their fields, more than 50% of the farmers answered that there was a difference in the *bari*, and about 50% answered there was in *khet* fields.

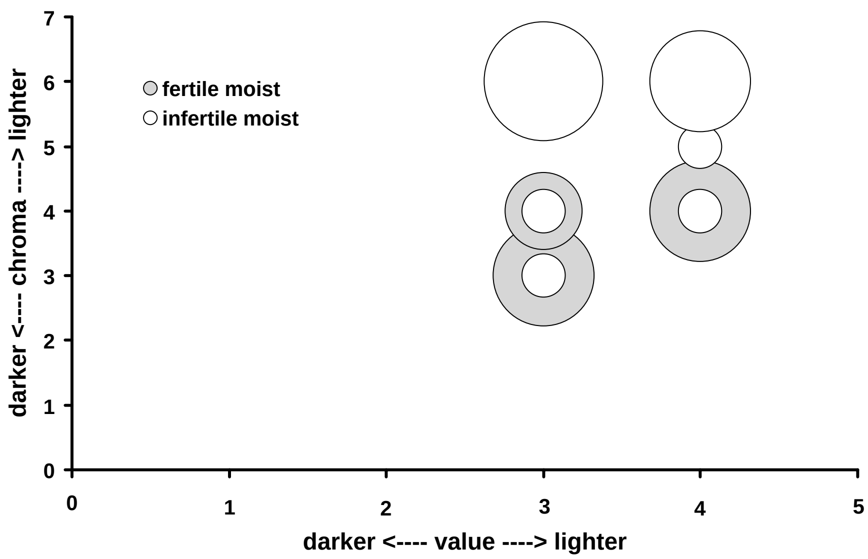

Fig. 3. Comparison of soil colour between fertile and infertile *bari* fields. The size of each bubble is proportional to the number of samples at the corresponding value/chroma combination.

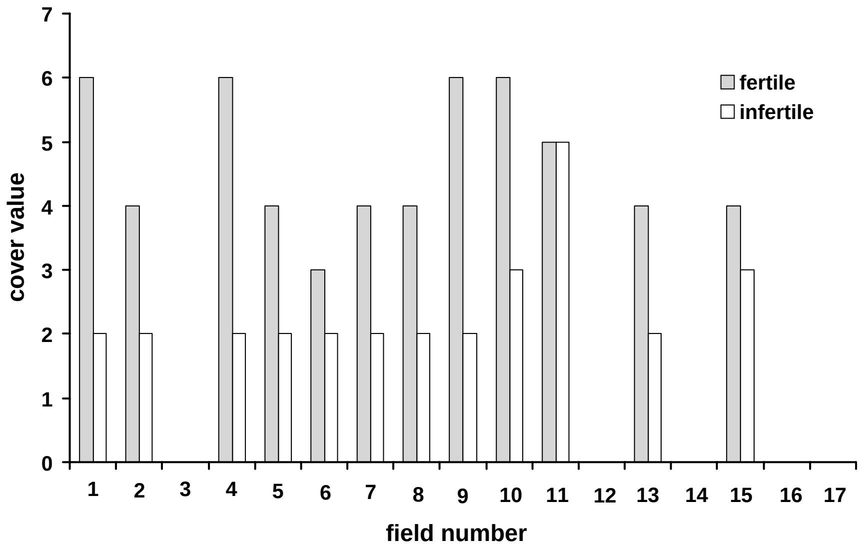

Fig. 4. General cover ranking of weeds in fertile and infertile *bari* fields.

Farmers who answered that weeds could be used as indicators in *bari* further explained (97%) that there was a higher abundance of weeds in the fertile *bari*. It was found that by abundance they mean diversity as well as cover. Furthermore, over half of the farmers (59%) found that species in the fertile and infertile *bari* were different. For *khet* fields, on the other hand, it was unclear from the results whether differences were due to the amount of water in the field or the fertility of the soil.

In the *bari* fields, it was found that there was a higher abundance and ground cover of agricultural weeds in the fertile fields than the infertile fields (Figs. 4 and 5). No clear trends could be established in the *khet* fields.

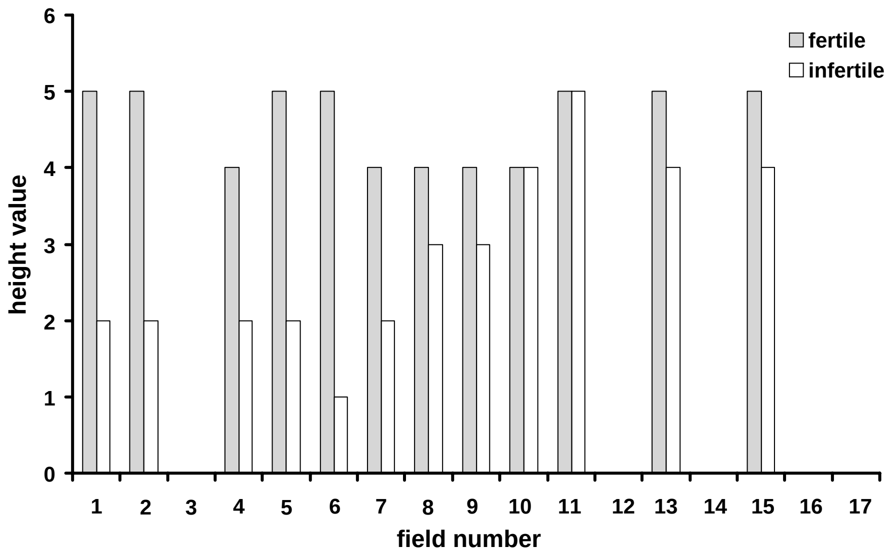

Fig. 5. Canopy height ranking of weeds in fertile and infertile *bari* fields.

Table 6
Principal weeds collected in *bari* fields and their preferred field fertility

Local name	Botanical name	Family	More abundant in:
Boke (white)	*A. conyzoides* L.	Compositae	Fertile fields
Boke (blue)	*Ageratum houstonianum* Mill.	Compositae	Fertile fields
Avijalo	*D. cordata* (L.) Willd. ex Schult.	Caryophyllaceae	Fertile fields
Rotnaulo	*P. nepalense* Meissn.	Polygonaceae	Fertile fields
Adikari	*G. parviflora* Cav.	Compositae	Fertile fields
Chitre bonsu	*Oplismenus* spp.	Graminae	Infertile fields
Bonsu	*Digitaria* spp.	Graminae	Infertile fields
Davile	*Brachiaria ramose* (L.) Stapf.	Graminae	Infertile fields
Kuro	*B. ramose*	Graminae	Infertile fields
Suire	*Imperata* spp.	Graminae	Infertile fields
Kaney	*Commelina diffusa* Burm.	Graminae	Infertile fields
Sama	*Echinochola* spp.	Graminae	Infertile fields
Gorre dubo	*Cynodon dactylon* (L.) Pers.	Graminae	Infertile fields
Rote	*C. dactylon*	Graminae	Infertile fields

In lower Pakuwa, some fertile *bari* fields could not be included in the analysis as weeds had been so abundant that they had been gathered as fodder for the livestock. The infertile fields, however, had not been weeded, suggesting that there were less weeds in these fields.

Table 6 shows the weed species identified in the *bari* fields. In upper Pakuwa, rotnaulo (*Polygonum nepalense* Meissn.), and adikari (*Galinsoga parviflora* Cav.) were more abundant and had a higher cover in the fertile fields and would appear to also be good indicators of soil fertility. These plants were not as abundant in lower Pakuwa. This is due to the difference in altitude as these plants are known to occur primarily above 1000 m (Parker, 1992). Avijialo (*Drymeria cordata* (L.) Willd. ex Schult.) was also well correlated to soil fertility in the uplands. Generally, it was observed that fertile fields had more weeds of the Compositeae family and infertile fields more Gramineae. This supports farmers' views that bonsu (*Digitaria* spp.), siru (*Imperata cylindrica* (L.) Raeusch), suire (*Imperata* spp.) and other types of grasses were more common in the infertile fields.

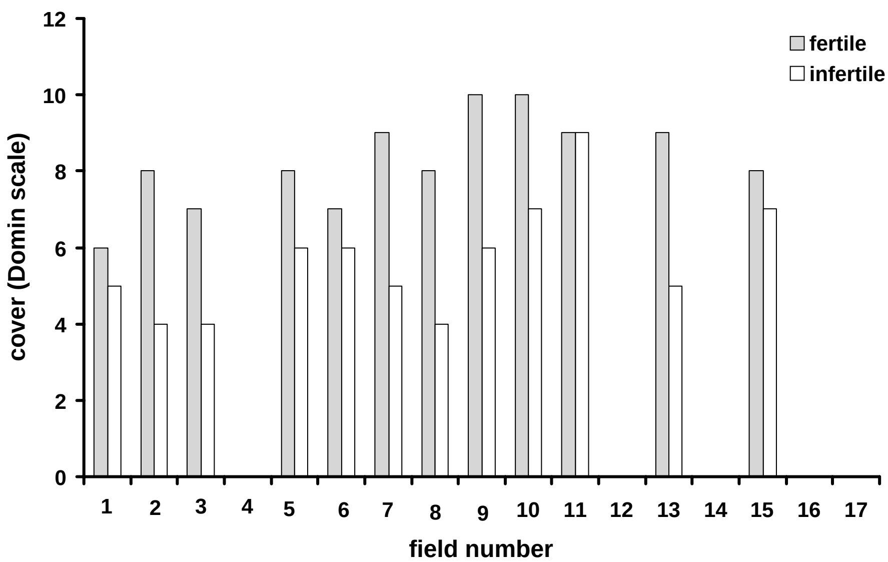

Fig. 6. *A. conyzoides* cover in fertile and infertile *bari* fields.

The species *boke jhar* (*A. conyzoides* L.) was found to be a good indicator of soil fertility in *bari* fields, where it was clearly more abundant, taller and had more foliage in fertile fields (Fig. 6). While the abundance of some weed species depended on the altitude, *A. conyzoides* was found in both the uplands and lowlands.

5. Discussion

It is clear from this study that farmers in the mid-hills of Nepal have a well-defined and comprehensive set of indicators that they use to classify and assess the fertility of their soils. Generally, these are characteristics they can see, feel, or smell in their fields, and are based on their own experiences in cultivating the fields. Similar indicators have been identified by studies in other parts of the world. In Niger, for example, farmers distinguish three major soil types: *jigawa*, *geza* and *hako* on the basis of indicators such as soil texture, reactions to precipitation and runoff, and workability with agricultural tools (Ambouta et al., 1998). *Jigawa* soils have a clear topsoil layer, and they are permeable and easy to work with tools, *geza* soils are a deeper red and rapidly waterlogged during rainstorms, while *hako* soils are compact, impermeable, quite hard when dry, and difficult to work. Similarly, in the Siaya District of Kenya, farmers base their classification on the surface layer of the soil, taking into account the colour, texture, and heaviness of working (Mango, 2000). Indicators used to assess the current fertility of a field included crop yields, soil colour, compactness, soil odour and the composition of vegetation. In another part of Kenya, farmers' criteria for distinguishing soil productivity also included ease of tillage, soil moisture retention, and the presence of weeds and soil invertebrates (Murage et al., 2000). The presence of earthworms and beetle larvae were regarded as positive features. The weed *Commelina benghalensis* (L.) was associated with soils of high productivity, and *Digitaria scalarum* Schwein. and *Rhynchelytrum repens* Willd. with low productivity soils. In northern Ethiopia (Corbeels et al., 2000) three different soil types are distinguished by farmers according to yield, topography, soil depth, colour texture, water holding capacity, and stoniness. In southern Rwanda, soils are classified by their agricultural potential and tillage properties into nine major soil types based on criteria such as crop productivity, soil depth, soil structure, and soil colour (Habarurema and Steiner, 1997). More experienced, older farmers are capable of further subdividing these nine types into sub-classes and groups by taking into account indicator plants, soil texture and consistence, and parent material.

In all of these studies, soil colour is the most widely used indicator used by farmers to classify their soils. This was also the case in our study—black soils (*kalo mato*) (including so-called 'white soils' (*seto mato*) if silica is present) are the most fertile, and red soils (*rato mato*) are the least fertile. Similar findings were obtained by Tamang (1992) and Turton et al. (1995), although Tamang (1992) makes the point that the importance of colour or texture in soil classification can vary, and depends on the area and ethnic group considered.

Although weeds were not spontaneously mentioned by farmers in our study as indicators of soil fertility in *bari* fields, most of them recognised that there are more present in the fertile fields than infertile. This view is supported by both visual observations and from the quadrat sampling. In *bari* fields, where management practices are relatively uniform, weeds (in particular *A. conyzoides*) can be used as an indicator of soil fertility. In *khet* fields, with much more varied management practices, no clear results were obtained, and irrigation regime and water levels are probably more important in influencing weed distribution and abundance than soil fertility. Other authors have also noted that the ability of weeds to act as unambiguous indicators is limited, because their presence may reflect cropping practices rather than soil conditions (Corbeels et al., 2000). Nevertheless, reports on the use of weed growth and weed species as indicators of soil fertility in other parts of the world are widespread. For example, they are used to identify areas of good agricultural potential (e.g. Barrios et al., 1994; Fujisaka et al., 2000), environmental conditions (e.g. Holzner, 1971; Ramirez et al., 1991) or to detect soil impoverishment after cropping (e.g. Bannink and Leijs, 1974; Sakai and Kawanabe, 1982; Otte, 1984; Kranz et al., 1998; Corbeels et al., 2000; Fujisaka et al., 2000; Mango, 2000; Murage et al., 2000).

It was clear from the number, diversity and descriptive detail of the indicators identified in our study, as well as from the interviews, that Nepali farmers have both an intimate knowledge and 'holistic' view of soil fertility, being more interested in their fields' ability to produce crops rather than in soil fertility per se. In some ways, the concept of 'field fitness' is more appropriate than 'soil fertility' in understanding how farmers think, as they regard their soils as one component within a particular environmental context and location. Fitness, as opposed to the terms 'quality' or 'health' that are sometimes used (e.g. Roming et al., 1995), emphasises the overall ability of a field to perform particular functions, mainly crop production, under a particular management regime and environmental constraints.

One interesting finding of this study was the importance of environmental factors mentioned as indicators by farmers. These included such factors as the amount of water bringing nutrients from forested areas higher up, the occurrence of a landslide, and even the level of crop destruction in a field by monkeys, all of which would affect the fertility management of the field by the farmer. The importance of the local environment in farmers' perception of soil fertility is not widely reported, although Corbeels et al. (2000) noted that farmers in Ethiopia mentioned topography while Tamang (1992) and Turton et al. (1995) both mention slope and altitude from discussions with farmers about soil fertility in the hills of Nepal.

It was also clear that farmers see soil fertility as a dynamic process integrating the soil's chemical and physical characteristics, its agricultural requirements, and factors in the surrounding environment. More importantly, they see themselves as active participants in this process. For example, in a similar study in Nepal, Tamang (1992) reports that farmers claim that 'any soil can be made fertile'. The same concept was found in Niger—where intensification on the fertile *jigawa* soils resulted in soil fertility decline, these soils began to be referred to as *hako* soils (Ambouta et al., 1998). However, when improved soil management techniques were adopted, particularly working the topsoil layer and mulching, many *hako* soils were re-transformed back into *jigawa* soils. A similar view of the dynamic nature of soil classification is taken by farmers in the semiarid highlands of Tigray, northern Ethiopia (Corbeels et al., 2000), who see their land moving between the *reguid* (fertile soils), *mehakelay* (moderately fertile soils) and *rekik* (poor soils) classifications depending on how it is managed. This fits with the view expressed by some authors (e.g. Williams and Ortiz-Solorio, 1981; Roming et al., 1995) that soil fertility is a human-made technical attribute rather than an inherent soil property. Indeed, a comparison of the fertility status of forest and cultivated soils in Nepal suggests that farmer management has acted to increase the soil fertility far beyond their inherent levels (Schmidt et al., 1993). Human activity has resulted in a concentration of nutrients on cultivated lands, and it is only natural that farmers include themselves and their environment in their interpretation of soil fertility.

Although farmers are often described as practising short-term strategies and having only short term views regarding soil fertility (e.g. Turton et al., 1995), our study indicates that this is not the full story. Indeed, the number of indicators identified which were medium or long term in nature (Table 3) suggests that farmers do have a significant long-term perspective. In the interviews, we found often that farmers would describe long-term soil management strategies for each of their individual fields, and then show fields that had been infertile 10 years ago but through careful management had been made fertile.

The holistic view of soil fertility of farmers differs from the more reductionist view of many researchers. Farmers are interested in soil productivity and appropriate management practices, and as such, generally only take the topsoil or the arable layer into account. Similarly, their classification and indicators rely on soil characteristics that they can experience, so that the names they give to soils do not necessarily correlate to the scientific classification, particularly at the national and international levels. Researchers, on the other hand, are usually more interested in the way the soil was formed, or in things that they can measure and which are not always visible (e.g. soil N content). In addition, they may also rely on agricultural models, methods and techniques conceived in the context of the industrialised world and which are not necessarily wholly appropriate in a developing country context (Pawluk et al., 1992). Nevertheless, both farmers and researchers have similar objectives, namely to ensure that the soil resources are sufficient to meet the needs of present day farmers and also the farmers of the future. It is important, therefore, that both perceptions of soil fertility are used. For this to occur, researchers need to understand and use indigenous knowledge systems, which need to be viewed, not as opposing, but rather as complimentary to their own way of thinking (Pawluk et al., 1992).

The results presented in this paper indicate that there is good agreement between assessment of soil fertility by farmers in Nepal and scientific indicators of soil fertility such as nutrient status, soil organic matter content, and pH. Similar agreement has been found in other studies—for example, Murage et al. (2000) found in Kenya that productive soils, as identified by 12 farmers, had significantly higher soil pH, effective cation exchange capacity, exchangeable cations, extractable P, and total N and P than non-productive soils. Total organic C and several estimates of soil labile C including particulate organic C (POC), three Ludox density separates of POC, $KMnO_4$-oxidisable C, and microbial biomass C were also significantly greater in the productive soils, as was soil microbial biomass N, net N mineralisation and soil respiration. The similarity of soil physical properties (clay and sand contents) in productive and non-productive fields suggested that differences in chemical and biological indicators had resulted from soil management and were not inherent properties of the soils. In a similar study in the Tharaka Nithi District in Kenya, Iringu et al. (1996) found that total organic C differed significantly between soils classified as good and poor by farmers there, but, interestingly, that there were no significant differences in soil pH. Similarly, Corbeels et al. (2000) found that the classification used by farmers in the semiarid highlands of Tigray, northern Ethiopia, discussed above, correlated well with the categories of soil fertility.

In southern Rwanda, however, no clear correlation was found between soil types according to farmers' classification and soil types classified according to the US Soil Taxonomy (Habarurema and Steiner, 1997), reflecting the different ways in which farmers and scientists categorise soils. However, within the three agroecological zones situated in different districts of the study area, farmers always applied the same names, the use of which facilitated exchange between farmers, extension workers and researchers. Farmers' soil classes correspond to soil suitability classes, and may therefore be useful for land evaluation systems.

In the USA, Liebig and Doran (1999) compared farmers' knowledge of soil quality to indicators determined by the established assessment protocol. Twenty-four conventional and organic farmers throughout eastern Nebraska, USA, were paired within regions of similar climate, topography, and soil type, and their perceptions of soil conditions for 'good' and 'problem' soils on their farms were queried using a written questionnaire. Their perceptions of soil quality indicators tended to match the scientific assessment closely for 'good' soils, but less so for 'problem' soils. Indicators that were incorrectly estimated at a frequency greater than 33% included available N and P, soil colour, degree of compaction, and infiltration rate. Despite this, farmers' perceptions were correct or nearly-correct over 75% of the time for the majority of indicators evaluated in the study.

Thus, evidence is emerging that there is sufficient overlap between farmers' and researchers' perceptions of soil fertility for there to be useful dialogue. Similar overlaps in knowledge were observed in Himachal Pradesh in India by Duffield et al. (1998) in a wider context than just soil fertility. Indicators of sustainability identified by villagers tended to emphasise their livelihood dependence on the surrounding forest, whereas those identified by local professionals placed greater emphasis on the presence or absence of forest management practices as indicators of sustainability. The latter also gave more weight to agroforestry and agricultural diversification and stressed a different mix of socio-economic indicators. Overall, however, there was significant agreement on most of the basic concepts. In the Nepal context, the expertise of both farmers and researchers is important if more sustainable techniques of soil management are to be devised an implemented. Researchers can provide the breadth of understanding of soil biophysical processes gained from experiences world-wide, whereas farmers can provide the context-specific knowledge required to adapt this understanding to local biophysical and socio-economic conditions. Local agricultural extension staff can play an important role in enhancing this essential link between the two worlds.

Acknowledgements

The authors are indebted to all the farmers of upper and lower Pakuwa who shared their time and knowledge to patiently explain their understanding of soil fertility. AD is particularly grateful to Mr. Thakur Paudel and his family for their hospitality and generosity as well as Debendra Rimal for his assistance during the field work. Acknowledgement is also due to Dilliram Devkota and Budhi B. Pant from ARS for the soil analysis and to Keshav Devkota of the Agronomy Division, NARC, Khumaltar, for his help in identifying agricultural weeds. The assistance of Dr. R.P. Sah, Station Chief of ARS Lumle, and Dr. W.T. Stewart-Jones, Research Advisor, Hill Agriculture Research Project (HARP) of the British Government, is also gratefully acknowledged.

Financial support for this study was provided by the Gilchrist Charity, and by the Natural Resources Systems Programme (project No. R7536) of the United Kingdom's Department for International Development (DFID). The views expressed are not necessarily those of the Gilchrist Charity or of DFID.

References

Acharya, G.P., Tripathi, B.P., Shrestha, S.P., Gregory, P.J., 2000. Nutrient management in maize–finger millet systems in the hills of Nepal. Lumle Seminar Paper No. 2000/8. Agriculture Research Station Lumle, Pokhara, Nepal.

Ambouta, J.M.K., Amadou, I., Souley, I., 1998. Soil fertility changes and management in Gakudi (Maradi, Niger). Cahiers Agric. 7, 395–400.

Bannink, J.F., Leijs, H.N., 1974. Weeds as environmental indicators, especially of soil conditions. Verslagen van Landbouwkundige Onderzoekingen, Wageningen Agricultural Research Reports. Wageningen Agricultural University, Wageningen, The Netherlands.

Barrios, E., Herrera, R., Valles, J.L., 1994. Tropical floodplain agroforestry systems in mid-Orinoco River basin, Venezuela. Agrofor. Syst. 28, 143–157.

Corbeels, M., Shiferaw, A., Haile, M., 2000. Farmers' knowledge of soil fertility and local management strategies in Tigray, Ethiopia. Managing Africa's Soils 10, ii + 23.

Duffield, C., Gardner, J.S., Berkes, F., Singh, R.B., 1998. Local knowledge in the assessment of resource availability: case studies in Himachal Pradesh, India, and British Columbia, Canada. Mountain Res. Develop. 18, 35–49.

Fujisaka, S., Escobar, G., Veneklaas, E.J., 2000. Weedy fields and forests: interactions between land use and the composition of plant communities in the Peruvian Amazon. Agric. Ecosyst. Environ. 78, 175–186.

Habarurema, E., Steiner, K.G., 1997. Soil suitability classification by farmers in southern Rwanda. Geoderma 75, 75–87.

Holzner, W., 1971. Field weeds in lower Austria as indicators of environmental conditions. Bodenkultur 22, 397–414.

Iringu, J.W., Warren, G.P., Sutherland, A., 1996. Soil fertility status in small-holder farms in the semi-arid areas of Tharaka Nithi District: farmers' assessment compared to laboratory analysis. In: Proceedings of the Fifth Scientific Conference of the Kenya Agricultural Research Institute, Nairobi, Kenya, October 30–November, 1996.

Keatinge, J.D.H., Qui, A., Wheeler, T.R., Subedi, M., Shah, P.B., Ellis, R.H., Summerfield, R.J., 1999. Annual legume species as green manures/cover crops in low income farming systems of Nepal. Mountain Res. Develop. 19, 325–332.

Kranz, B., Fugger, W.D., Kroschel, J., Sauerborn, J., 1998. The influence of organic manure on *Striga hermonthica* (Del.) Benth. infestation in northern Ghana. Adv. Geoecol. 31, 615–619.

Liebig, M.A., Doran, J.W., 1999. Evaluation of farmers' perceptions of soil quality indicators. Am. J. Alternat. Agric. 14, 11–21.

Mango, N.A.R., 2000. Integrated soil fertility management in Siaya District, Kenya. Managing Africa's Soils 7, ii + 28.

Murage, E.W., Karanja, N.K., Smithson, P.C., Woomer, P.L., 2000. Diagnostic indicators of soil quality in productive and non-productive smallholders' fields of Kenya's Central Highlands. Agric. Ecosyst. Environ. 79, 1–8.

Otte, A., 1984. Arable weeds as indicators of nutrient status in the region of Ingolstadt. Verhandlungen der Gesellschaft dur Okologie 12, 255–268.

Parker, C., 1992. Weeds of Bhutan. National Plant Protection Centre Simtokha, Royal Government of Bhutan. Sayce Publishing, London.

Pawluk, R.R., Sandor, J.A., Tabor, J.A., 1992. The role of indigenous soil knowledge in agricultural development. J. Soil Water Conserv. 47, 298–302.

Ramirez, G.C., Finot, S.V., Martin, P.C.S., Ellies, S.A., 1991. The ecological indicator values of the south-central Chilean weeds. Agro-Sur 19, 94–116.

Roming, D.E., Garlynd, M.J., Harris, R.F., McSweeney, K., 1995. How farmers assess soil health and quality. J. Soil Water Conserv. 50, 229–236.

Sakai, H., Kawanabe, S., 1982. Ecology of grassland weeds in Japan. Jpn. Agric. Res. Quart. 16, 29–37.

Schmidt, M., Schreier, H., Shah, P.B., 1993. Factors affecting the nutrient status of forest sites in a mountain watershed in Nepal. J. Soil Sci. 44, 417–425.

Schreier, H., Shah, P.B., Lavkulich, L.M., Brown, S., 1994. Maintaining soil fertility under increasing land use pressure in the middle hills of Nepal. Soil Use Manage. 10, 137–142.

Shimwell, D.W., 1971. The Description and Classification of Vegetation. University of Washington Press, Washington.

Shrestha, B., Maskey, S.L., Shrestha, R.K., Tripathi, B.P., Khadka, Y.G., Munankarmi, R.C., Bhattari, E.M., Shrestha, S.P., 2000. Soil fertility management: farmers' practices and perception in the hills of Nepal. Lumle Technical Paper No. 2000/4. Lumle Agriculture Research Station, Pokhara, Nepal.

Tamang, D., 1991. Indigenous soil fertility management in the Jhihku Khola watershed. In: Shah, P.B., Schreier, H., Brown, S.J., Riley, K.W. (Eds.), Soil Fertility and Erosion Issues in the Middle Mountains of Nepal. Proceedings of the Workshop on the Jhikhu Kola Watershed, Nepal, April 22–25, 1991, pp. 3–14.

Tamang, D., 1992. Indigenous soil fertility management in the hills of Nepal: lessons from an east–west transect. Report No. 19. HMG Ministry of Agriculture/Winrock International Research.

Thapa, B., Walker, D.H., Sinclair, F.L., 1997. Indigenous knowledge of the feeding value of tree fodder. Anim. Feed Sci. Technol. 67, 97–114.

Turton, C.N., Vaidya, A., Tuladhar, J.K., Joshi, K.D., 1995. Towards sustainable soil fertility management in the hills of Nepal. Lumle Agricultural Research Center, Nepal/Natural Resources Institute, Chatham Maritime, UK.

Williams, B.J., Ortiz-Solorio, C.A., 1981. Middle American folk soil taxonomy. Ann. Assoc. Am. Geogr. 71, 335–358.

World Bank, 2001. World Development Indicators. World Bank, Washington.