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IMPLICATIONS OF HILL FARMERS' AGRONOMIC PRACTICES IN NEPAL FOR CROP IMPROVEMENT IN MAIZE

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SUMMARY

An agro-ecological analysis of the maize component of an agroforestry system in the eastern mid-hills of Nepal was conducted in 1999. The aim of the study was to understand farmers' current maize cultivation practices as a prerequisite to development of maize varieties that are better adapted to local conditions than the improved varieties currently on offer from conventional maize breeding programmes in Nepal. Practices of 50 smallholder farmers were surveyed in three villages, and the response of the maize crop was recorded. The study revealed great variability in agronomic practices, and in particular, farmers' maize husbandry differed markedly from national recommendations for plant population, agronomic inputs and genotypes used. Farmers regularly employed practices that were not even officially recognised by the national research and extension services, such as thinning of maize for livestock fodder, growing the crop in association with trees for fodder, and relay cropping with finger millet, their priority being to optimize overall output of the farming system rather than maximizing maize productivity. Reasons for deviations from recommended practices are analysed and implications for maize crop improvement for heterogeneous conditions are discussed.

INTRODUCTION

Maize (*Zea mays*) is the most important cereal crop in the mid-hills and is second only to rice in the national context in terms of both the area cultivated and production achieved in Nepal (CBS, 2000). Of the 819 000 ha of maize grown in Nepal, 69 % is grown in the mid-hills (Adhikari *et al.*, 2002). More than two-thirds of the maize produced in the hills is used for direct human consumption at the farm level, and in the eastern mid-hills it provides 48 % of food requirements (by weight). Significant amounts (approaching 30 %) are sold as grain and/or made into saleable beverages (Paudyal *et al.*, 2001). However, the productivity of maize in the mid-hills, which is slightly above 1.7 t ha^{-1} (CBS, 2000), has either been declining or static over the last two decades (NMRP, 1997), for three main reasons:

- soil erosion;
- decreasing applications of manure-based compost as a result of a government policy prohibiting farmers from collecting fodder from forests leading to reductions in the number of livestock per farm; and

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- low adoption of new maize varieties with higher potential yield released by the national maize breeding programmes.

Bari land is defined as being rain-fed with unbunded terraces, generally located on the upper slopes of the mid-hills. In contrast *khet* land, generally on lower slopes, consists of bunded terraces that are irrigated and predominantly used to grow rice. Hillsides are steep; terraces follow the contours and are typically five or six metres from back to front. More than 70 species of trees used for fodder and fuel have been recorded on terrace risers in a single village in the eastern mid-hills (Thapa *et al.*, 1997) while 111 species were recorded on farms in the western mid-hills (Carter, 1992), and cover is increasing over time. These trees are a valuable reservoir of biodiversity, in addition to meeting immediate farm needs. Between 1100 and 1750 m altitude, finger millet (*Eleusine coracana*) is relay transplanted under standing spring-sown maize, and more than 85 % of the finger millet in Nepal is grown in combination with maize (Subedi, 1996). The negative aspects of this multistrata agroforestry system for maize, including competition for soil nutrients, soil moisture, and light, are more widely reported than the positive aspects, which are also are recognized and well understood by farmers (Thapa *et al.*, 1995). Most of the positive aspects are only appreciated from a systems perspective. These include meeting farmers' multiple objectives for crop yield and fodder and fuel while controlling soil and maintaining organic matter (OM) content of soil through manure inputs.

The understanding of interactions between maize/millet and trees under the unpredictable environmental conditions that prevail in the hills is still in its infancy, and studies have been few (Thapa *et al.*, 1995; Joshi and Devkota, 1996). Previous workers have reported that shade negatively affects maize growth and development in monocultures under well-controlled experimental conditions (Earley *et al.*, 1966; Reed *et al.*, 1988; Andrade *et al.*, 1993; Ephrath *et al.*, 1993; Odhiambo *et al.*, 1999; Lott *et al.*, 2000). There is also an increasing realisation that technical progress has been constrained by a lack of understanding of relationships between trees and crops (Chamshama *et al.*, 1998).

The initial selection stages for currently available maize varieties in Nepal were conducted on research stations under high input conditions. However, the physical constraints imposed by the terrain and variations in the environment in the mid-hills make the planning of research and development programmes difficult, requiring more thought than in more homogeneous environments. The traditional technology-generation approach used for high input monocultures does not take into account the complexity of the system and farmers' multiple goals for maize production. Past research has largely targeted favourable environments, and findings do not transfer well to the marginal environments of resource-poor farmers such as those described in this paper. Variability with respect to bio-physical and socio-economic circumstances have often been ignored in agricultural research, making recommendations based on this conventional research of questionable relevance to farmers experiencing marginal conditions (Scoones and Thompson, 1994; Scoones, 1996). Consequently recommendations of research institutions are not adopted by the majority of the hill farmers.

The understanding of the rationale underlying farmers' practices is one step in a process aimed at improving the productivity of the system. Accordingly, this agro-ecological study sought to understand farmers' responses to the variability of their environment in terms of agronomic manipulations, and also reports the response of the maize crop to such variability. Knowledge of farmers' responses to this variability, some of which is controlled by farmers and some being outside their control, will result in greater relevance of future adaptive research planning decisions. Site characterization and the process of elicitation of farmers' indigenous technical knowledge are the subjects of other publications (Tiwari *et al.*, 2000a, 2000b).

MATERIALS AND METHODS

Site selection

The research was carried out at three sites representative of conditions in the eastern mid-hills of Nepal. The criteria used to select sites were that:

- they were located in the mid-hills (altitude 1100 m to 1750 m above sea level);
- the predominant cropping on *bari* land was maize/millet relay cropping with fodder trees on crop terrace risers;
- maize was a staple food and a significant source of income;
- there were no political or social hindrances restricting effective farmer-researcher interaction; and
- there was a long history of maize production.

On the basis of these criteria Marga (M) and Patle (P) villages in Dhankuta district, and Fakchamara (F) in Tehrathum district in the eastern mid-hills were chosen. Well before the maize season started, farms were visited and assessed for whether the land was representative. Only those farmers willing to co-operate were selected to participate in the study.

Characterisation of agronomic practices

This study was carried out in summer 1999 on *bari* terraces with east and southeast aspects in 15 farmers' fields each in Marga and Patle, and 20 farmers' fields in Fakchamara. The selected farms were widely distributed through the villages. Farmers were randomly chosen from those listed in village records. Key informants, comprising village leaders and outreach workers from the Agricultural Research Station, Pakhribas (ARSP) based in the village, then categorized the selected farmers in terms of wealth according to standard criteria established at ARSP (Joshi and Rai, 1993). This was done on the basis of food availability for household consumption and divided into five different categories. Category A = food available for more than 12 months, B = food available only for 12 months, C = food available for from six months to 12 months, D = food available for less than six months.

Selected households were visited and the objective and duration of the study, and expected co-operation required from them were explained while basic information about the land holding was collected. An effort was made to explain that the researchers were there to learn about the maize production system from the farmers themselves. Their *bari* land terraces were visited to confirm that the land was representative.

The mean annual rainfall at the nearby Agricultural Research Station, Pakhribas, is 1670 mm, of which 87 % occurs between May and September (Gurung and Resham, 1993). Fields of variable sizes, between 500 m^2 and 2000 m^2, were demarcated for the study of agronomic practices; one field per farm. Varieties, seed sources, and quantities of seed, compost and chemical fertilizers applied to these demarcated areas were recorded in local units. They were then converted into metric units using the following conversion factors:

One 'Doko' (conical bamboo basket) compost = 24 kg;

One 'Pathi' maize = 3.13 kg.

The proportion of varieties grown by farmers was calculated on the basis of total farm area covered by maize divided by the area covered by each variety.

Composite soil samples were collected from Marga and Patle before maize sowing for chemical analysis, sampled at furrow depth from various locations within the farm, depending on size, shape and number of terraces, and reduced to 1 kg for each farm by normal sampling and mixing techniques. Nitrogen and phosphorus were determined by spectrophotometery and potassium by flame photometery in acid digested samples. The total nitrogen was determined by the Kjeldahl procedure. Available phosphorus was determined by the Bray-1 method (Anderson and Ingram, 1993). Compost samples were also taken from top, bottom and middle of the compost heap from each farm.

In order to determine the effect of trees on maize, six plots measuring 3 × 3 m were demarcated within each of the selected fields just after maize sowing, three in close proximity to trees (under shade = US) and three away from the influence of tree shade (outside shade = OS). A buffer of 2 m from the starting corner point of the terrace and 0.25 m from the outer edge of the terrace was left.

Maize plant population was determined at one month intervals, from emergence to harvest. Other agronomic data collected were duration to maturity, height at anthesis, disease incidence and occurrence (this was scored on 1–5 scoring scale where 1 = free of disease; and 5 = severely infected) and final fresh biomass (dry weight was not possible due to transportation issues and weather conditions) and air-dry grain yield. Land preparation, sowing time, time of earthing up, thinning and other practices of farmers were recorded and reasons for these operations investigated using semi-structured interviews with farmers during the course of the study. After examining the findings from the investigation of farmers' practices, eight farmers in each of Marga and Patle were asked to rank reasons for high seed rates and subsequent thinning.

Data analysis

Agronomic data from all sites were subjected to analyses of variance using Genstat v. 3.2 (Windows version). The data per farm were arranged to give a two treatment structure outside (OS) and under (US) shade. Farms served as replicates for the purpose of statistical analysis, and villages as blocks. The analysis was based on 30 observations each for Marga and Patle, and 40 observations from Fakchamara, each observation being the mean of three sub-plots. In the analysis of variance, the degrees of freedom (*d.f.*) were partitioned as farms (replicates) = 14, treatment (shade) = 1, error = 14 at Marga and Patle, and farms (replicates) = 19, treatment (shade) = 1 and error = 19 at Fakchamara. To determine whether there were effects of site, a combined analysis comparing villages was also carried out. Due to the unbalanced replication structure amongst sites, the GLM (general linear model) procedure was used. Lodging (%), barren plants per unit area and disease score data were transformed before analysis as data were skewed because of large numbers of zeros. To compare treatment means, the standard errors of the differences (*s.e.d.*) were computed, where appropriate. Ranked data on farmers' reasons for using high seed rates were tabulated and mean ranks and their standard errors were calculated.

RESULTS

Results are presented in two sections, comprising firstly a characterization of practices used by farmers to cultivate maize and how they varied according to location and farmer circumstances and secondly, the response of the maize crop to the combination of these practices and the environment.

Factors controlled by farmers

Land preparation. This varied from one location to another. Farms are usually fragmented into small parcels of land, and timing and type of field operations are influenced by accessibility and farmers' perception of the agricultural potential of the field. Ploughing using a simple wooden plough with a pair of bullocks was done two or three times, depending on the type of land, availability of labour and bullocks. Farmers who had heavy soils, small farms or who had their own bullocks ploughed their land three times. Harrowing by clod breaking and planking (where farmers stand on a plank hauled by a pair of bullocks) were done before maize sowing to create a tilth and ensure better germination and growth by conserving soil moisture. Farmers put less emphasis on land preparation if the *bari* land was considered to be marginal or less productive, or they had insufficient family labour or did not have their own bullocks. Those farmers who had access to adequate resources were found to be preparing land for maize well in advance of the season, just after harvesting finger millet (in December), to conserve soil moisture through the dry season. Farmers expressed the view that if land was prepared well in advance then there was a lower risk of poor germination, even if there was drought at sowing time.

Soil. According to the classification of Landon (1984) soils from both Marga and Patle had low nitrogen content (mean across two sites was 0.12 %, *s.e.m.* 0.01) and OM (1.29 %, *s.e.m.* 0.10) and the level of phosphorous was low to medium (24.0 ppm, *s.e.m.* 0.88). Mean pH was 5.3 (*s.e.m.* 0.06).

Composting and soil fertility maintenance. Application of compost to the maize crop was mostly done during sowing or just before land preparation. Forest litter, crop by-products and animal dung were mixed and put in a pit for several months to allow decomposition. Generally this was carried in a bamboo basket from the compost pit (near the homestead) to the field and heaped at points, from where some farmers spread it all over the field immediately after depositing it, while others waited until the time of land preparation.

The amount of compost used was variable amongst farmers and sites and not related to the quality of compost. In Fakchamara (mean application rate = 24.4 t ha^{-1}, *s.e.m.* 0.95) and Patle (24.0 t ha^{-1}, *s.e.m.* 1.84) farmers were found to be using more compost for their maize crop than at Marga (18.9 t ha^{-1}, *s.e.m.* 1.48). This was related to the availability of fodder trees, which consequently influenced the number of animals retained per farm. There was no relationship between the amount of compost used by farmers and its nutrient content. To take two examples, the highest amount of compost was applied by Mr Laxmi Subedi at Marga, which had a higher nutrient content (organic matter (OM) = 61.9 %; N = 1.51 %; P = 0.36 %; K = 3.0 %) than that of other farmers. On the other hand the lowest amount was applied by Mr Dil Bahadur Rana from Marga, but was also of low quality (OM = 35.2 %; N = 0.82 %; P = 0.031 %; K = 2.34 %). There was no significant linear correlation between the amount of compost applied and maize grain yield at Marga ($r = -0.28$, NS) and Patle ($r = 0.16$, NS), but there was a positive correlation at Fakchamara ($r = 0.47$, $p < 0.05$). Factors which tended to result in increased application rates were when maize was intercropped, land holdings were small, crops were planted on *bari* as opposed to *khet* land, new varieties were used, fields were closer to the homestead or compost pit, more family labour was available, there were more animals on the farm or there was greater access to the forest to collect leaf litter.

Besides compost, a minority of farmers (< 20 %) also used purchased inorganic fertilizer, mostly urea which was applied at a rate of 2 to 3 g $plant^{-1}$ around the maize root crown after major thinning was compete (equivalent to 46 to 86 kg N ha^{-1}), although a few farmers used muriate of potash (KCl) as a top dressing during the period of earthing up at 45–60 days after sowing (DAS). Urea was applied after the major thinning operation was completed (see section on thinning below). Some farmers reported that a satisfactory grain yield of maize could not be achieved without the use of chemical fertilizer, but also expressed awareness that the physical properties of soil were damaged by the continuous use of only chemical fertilizers, with soil becoming more difficult to plough and clods more difficult to break.

Seed source. Farmers predominantly use home-saved seed (95 % at Marga and 75 % at Patle). However, most farmers reported use of different seed sources for sowing on different parcels of their land. About 30 % of the farmers from both sites reported that they also obtained seeds from their neighbours and relatives. Although some reported buying fresh seed from the Agricultural Inputs Corporation, quantities were small and occasions generally infrequent.

Choice of variety. Names of maize varieties grown in Marga and Pale are shown in Table 1. Varieties grown varied between sites. Local white (white-grained) was the dominant variety grown by almost all farmers in Marga, whereas in Patle farmers referred to their most popular variety as Manakamana-1, a variety introduced to

Table 1. Proportion (%) of area sown to different maize varieties at Marga and Patle sites.

Varieties	Marga	Patle
Local white	68.2	38.0
Manakamana-1 (old seed)	19.3	55.2
Local yellow	0.0	5.0
Mixed (Gadbade)	12.0	0.0
Bikashe yellow†	0.0	1.5
Population-22†	0.0	1.2

† Bikashe yellow and Population-22 are new varieties under test in the area.

Nepal in 1986. However, farmers were not using fresh, certified seed of Manakamana-1 but were continuing with seeds that they saved after each season, it being typically seven to ten years since they had last purchased seed. Farmers reported that new varieties required higher inputs, were more susceptible to stress, particularly shade and drought, were more prone to diseases such as stalk and ear rots, the latter because of loose husks, stored grain pests and bird damage. Farmers also thought that local varieties germinated better in capped soil because they had thinner and more pointed coleoptiles than new varieties. Grain of local varieties was thought tastier than new varieties and their stover and husks more palatable to animals because of their thin stems and soft husks.

Seed sowing. Maize in the mid-hills is usually sown between the last week of March and the end of April, depending on the availability of resources. Those farmers who have their own bullocks sow immediately after rain and those who have no bullocks wait until their neighbours and relatives finish to borrow or hire them. However, in 1999 because of a prolonged drought (the longest for 35 years) there was almost a one and a half month delay in maize sowing. After the drought broke, the farmers mostly followed the broadcast method of seed sowing because of the then adequate moisture content in the soil. However, a few farmers at Fakchamara sowed maize behind the plough. In general, farmers said that they used behind the plough sowing for maize seed if the soil was deficient in moisture, to ensure germination. If there was a higher moisture content then they used the broadcasting method as it was faster. After it rained (24 May, 1999) there were no dry spells of significance and, therefore, little soil moisture deficit throughout the maize growing period.

Seed rate. Seed rate per unit area was found to be highly variable ranging from 35 to 111 kg ha^{-1} at Marga (mean = 58 kg ha^{-1}, *s.e.m.* 5.2); 44 to 110 kg ha^{-1} at Patle (64 kg ha^{-1}, *s.e.m.* 3.93); and 29 to 74 kg ha^{-1} at Fakchamara (51 kg ha^{-1}, *s.e.m.* 3.3). There was a distinct skewing towards lower seed rates, very high rates being the exception. There was no relationship between the seed rate used by farmers and size of land holding or soil nutrient content. Those farmers who had little land and were in food deficit for more than six months of the year were often found to be using a higher seed rate than farm households in food surplus, reflecting an attempt to grow more maize on

Table 2. Ranking of reasons given by farmers for using high maize seed rates.

Reasons for using a high seed rate	Marga (n = 8)	Patle (n = 8)	Overall (n = 16)
To use thinned plants as green fodder for livestock	1.6 (0.32)	1.0 (0.00)	1.3 (0.18)
To compensate for low germination rate due to inferior seed quality (although good seeds are selected and visibly bad ones discarded during sowing)	2.6 (0.38)	2.3 (0.16)	2.4 (0.20)
To mitigate against impacts of plant loss due to unpredictable weather	2.0 (0.19)	3.9 (0.13)	2.9 (0.27)
To mitigate against impacts of insect pests and diseases	5.1 (0.52)	3.0 (0.33)	4.1 (0.40)
To compensate for bird picking, generally maize seeds are broadcast, so most of the seeds remain on the soil surface	5.3 (0.16)	5.0 (0.19)	5.1 (0.13)
To mitigate against impacts of plant loss due to lodging	4.4 (0.26)	5.9 (0.13)	5.1 (0.24)

Numbers are mean ranks with standard errors in brackets.

a smaller area. The seed rates used by the farmers from Marga, Patle and Fakchamara were on average 190, 220 and 155 % higher than the national recommendation of 20 kg ha^{-1}. Their reasons for adopting high seed rates are summarised in Table 2. While there was broad agreement at both Marga and Patle about the importance of the need for plants to thin for fodder during the growing season and high seed rates to compensate for risk of low germination, compenstation for risk from pest attack was more prevalent at Marga while risk of bad weather was considered more important by farmers at Patle. Farmers used the same seed rate irrespective of the level of shade. The same reasons for high seed rates were given by farmers in Fakchamara but no formal ranking exercise was conducted to prioritize them.

Thinning. Farmers said that thinning of maize was a common agronomic practice. Most deliberate thinning of maize, that reduced the plant population significantly, was done when the crop was between the seventh and tenth leaf stage at 25 to 50 DAS. Only barren, diseased and lodged plants were thinned at later stages of crop growth. Farmers reported that they thinned maize plants primarily because of their high fodder value (Table 2) and because maize vegetative growth (April to June) coincides with the period before the monsoon is fully established, when green fodder is in short supply. Thinned plants were often fed to animals immediately after thinning, but if the quantity of thinnings was large then they were dried in the sun before feeding to avoid causing diarrhoea in the animals.

Weeding. The frequency of weeding and other maize field management practices was found to be highly variable amongst farms. In general, however, two weedings were done before finger millet transplanting in early August. The most commonly found weeds were 'Ratnaulo' (*Bistorta amplexicalis*), 'Ilame' (*Ageratum spp.*), 'Banso' (*Eragrostis tenella*) and 'Abijalo' (*Dirmeria cordata*). Farmers reported that, like most weeds in their maize fields, these were not a problem because of their high fodder value; exceptions included 'Dubo' (*Cynodon dactylon*), *Trifolium* spp. and *Cyperus* spp. which in their perception were either noxious or very difficult to remove and required frequent weeding because of their perennial and spreading habit. The first weeding was combined with thinning of maize, mainly intended to make the plant population more uniform over the field (to correct uneven establishment) and to remove major weeds. The second weeding, besides thinning maize and removing weeds, was intended to loosen soil for better aeration, and soil was heaped around the maize root crown, thereby encouraging prop root growth that was thought to protect maize from lodging due to wind or heavy rain. Gap filling was also sometimes done where the plant population was very low. Weeds were either fed to livestock or put in the compost pit.

Leaf stripping. Maize was generally relay intercropped with finger millet. During the time of finger millet transplanting or just before, mostly when maize silks were drying, farmers removed the bottom leaves of their maize plants, up to one leaf below the ear bracketing leaf. Reasons cited were various: the high fodder value of the stripped leaves, the reduction of shading on millet and to make millet transplanting operations easier.

Response of maize

Plant population. The plant population counts of maize at one month intervals for the three sites are presented in Figure 1. The effects of different farms within sites were significant on all five recording occasions. The mean populations at emergence were 102, 100 and 38 % higher than the national recommended population for maize of 53 300 plants ha^{-1} at Marga, Patle and Fakchamara respectively. In contrast, the final mean populations at harvest at the same sites were 45, 42 and 28 % less than the same national recommended plant population, indicating the extent of thinning during the season.

A combined analysis of variance showed there were strong effects of site upon plant establishment and population. Marga and Fakchamara, respectively, had the highest and lowest plant population count at emergence but these were reversed at harvest. Mean shade effects across all three sites were significant on all recording occasions, indicating that influence of shade (and farmers' management practices as a response to shading) were similar across sites. At Fakchamara, there was a significantly lower plant population under shade than in the open from emergence onwards, even though the same seed rate was used irrespective of shade. At Patle, lower populations under shade were significant from 30 DAS onwards, while at Marga there was no significant effect of shade until harvest.

Plant height. There were significant effects due to farm and shade at all sites and amongst sites (Table 3). Maize plants grown under shade were shorter, thinner and consequently weaker than those in the open. Farmers expressed the view that when maize was grown under sparse shade, it tended to be taller but when grown under dense shade, plant height was reduced.

Disease and insect pests. Diseases observed included ear rot (*Fusarium moniliforme*), stalk rot (*Erwinia carotovora*) and Turcicum blight (*Helminthosporium turcicum*). Insect pests noted

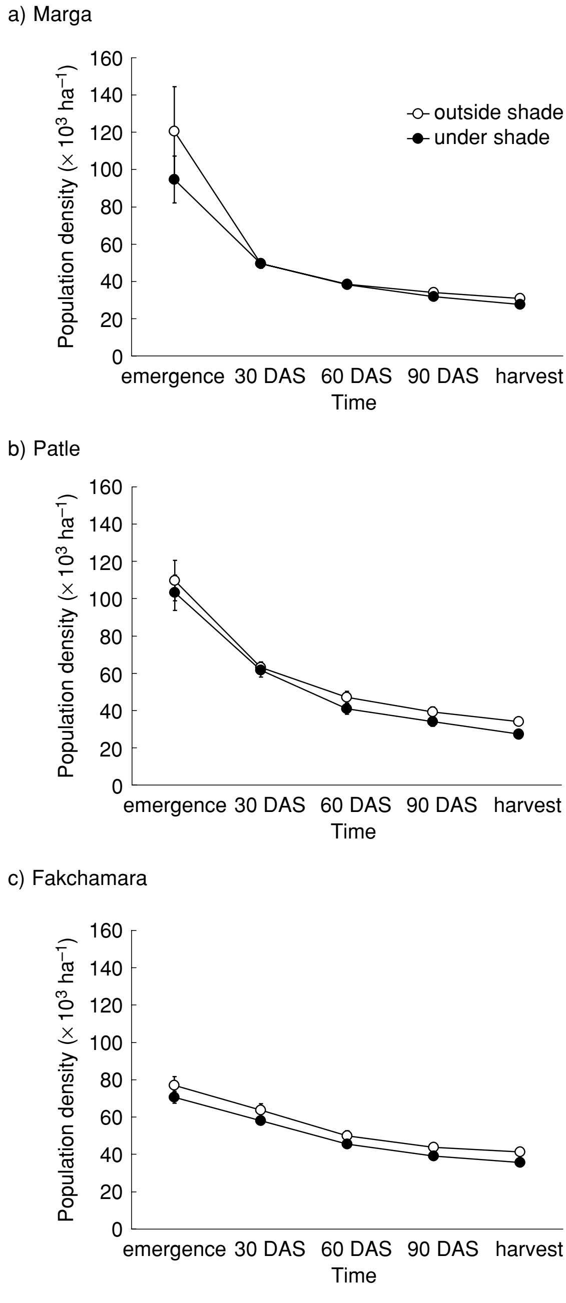

Figure 1. Variations in maize population density over time, under tree shade (US) and outside shade (OS) in farmers' field at three sites in the eastern mid hills of Nepal. DAS = days after sowing. Error bars = standard error of mean.

were white grub (*Holotrichia* spp.), stem borer (*Chilo zonelus*) and armyworm (*Mythimna separata*). In 1999, insect pest infestation was not that problematic at any of the three sites. Disease, mostly Turcicum blight which farmers commonly called

Table 3. Summary of analysis results of agronomic attributes, 1999.

Site	Effect	Plant height (cm)	Disease (scale 1–5)†	Lodging (%)†	Barren plants (ha^{-1})†	Duration (days)	Fresh biomass (t ha^{-1})	Grain yield (t ha^{-1})
Marga	Open	243	1.8 (1.16)	7.2 (2.42)	123 (1.22)	134	17.0	2.90
	Shaded	205	2.2 (1.21)	15.5 (3.74)	321 (2.34)	135	13.0	2.57
s.e.d.	Shade	6.79	0.015	0.220	0.49	0.51	1.00	0.172
	Farm	18.6	0.041	0.610	1.34	1.40	2.76	0.471
Patle	Open	240	2.3 (1.52)	12.0 (2.92)	222 (10.0)	128	18.2	3.41
	Shaded	214	2.9 (1.66)	15.0 (3.67)	864 (23.2)	130	11.0	1.81
s.e.d.	Shade	5.97	0.031	0.263	5.11	0.23	1.23	0.301
	Farm	16.4	0.085	0.720	14.0	0.64	3.36	0.823
Fakchamara	Open	296	2.4 (1.55)	14.0 (3.10)	241 (7.1)	127	19.2	3.81
	Shaded	275	2.9 (1.69)	21.0 (4.44)	759 (22.7)	129	14.0	2.53
s.e.d.	Shade	6.20	0.031	0.348	3.93	0.32	1.05	0.203
	Farm	19.5	0.098	1.102	14.4	1.04	3.33	0.642
Combined sites	Sites	4.11	0.020	0.190	2.58	0.24	0.71	0.148
	Shade	3.35	0.017	0.160	2.11	0.19	0.58	0.121

† Data were transformed (square root) before analysis, *s.e.d.* presented are from transformed data.
Data in parenthesis are transformed values.

'Ranke' or 'Dadhuwa' (literally meaning burnt) was found in all farmers' fields in 1999. There was a consistent influence of shade on disease occurrence across locations, with a significantly higher level of infection in all three sites under shade than in the open (Table 3).

Lodging. Farmers reported lodging due to wind as a major problem in maize cultivation. Most varieties grown were tall, and on none of the farms was maize found to be free from lodging. Degree of lodging and maize plant height were both higher at Fakchamara than at the other two sites. The amount of lodging was significantly higher ($p < 0.001$) under shade than outside shade, but was not correlated with differences in height under and outside shade (Table 3). Lodged plants were thinned unless lodging occurred near to physiological maturity when farmers would support lodged plants by tying them to non-lodged plants.

Barrenness. Farmers described barrenness as when maize ears either partially or fully failed to set grain and this was one of the commonest problems that they reported. In the present study, only those ears that had completely failed to set grain were counted as barren. Results indicated that the problem of barrenness at Marga was sporadic and less severe than at Patle and Fakchamara (Table 3). Shade effects were significant, with far more barren plants recorded from shaded plots. The combined analysis of variance revealed that site effects were also significant. The higher number of barren plants at Patle and Fakchamara than at Marga was consistent with the greater number of fodder trees on *bari* terraces.

Duration. Duration was recorded as the time from sowing until 95 % plants showed signs of physiological maturity indicated by brown or black layer formation in the seed and then confirmed with farmers. Maturity differed significantly in response to shade at the Patle and Fakchamara sites ($p < 0.001$) but not at Marga, maize grown under shade maturing a few days later than in the open. Site effects ($p < 0.001$) were significant and there was also an interaction effect of site × farm ($p < 0.001$).

Fresh biomass yield. The quantity of fresh biomass was an important attribute to farmers, who used the stover for livestock feed. There was an effect of farm and shade within farms on fresh biomass production at Marga ($p < 0.05$) and Fakchamara ($p < 0.01$), but not at Patle. Overall, fresh biomass was higher ($p < 0.05$) at Fakchamara than the other two sites and higher in the open than under shade ($p < 0.001$) consistent with greater plant height and higher plant populations. Site × shade interaction effects were not significant, suggesting that the influence of shade was consistent across sites (Table 3).

Grain yield. There were consistently higher yields in the open than under shade at all sites, with yield reduction due to shade being 11, 47 and 44 % at Marga, Patle and Fakchamara respectively (Table 3). The mean yield at Fakchamara was higher than both Marga and Patle, which were not significantly different from one another. Between farm effects were not significant ($p < 0.05$) at Marga and Patle, but were at Fakchamara ($p < 0.01$). Site × shade interaction effects were not significant, indicating a consistent effect of shade across sites.

DISCUSSION

The results are discussed by first detailing discrepancies between official recommendations and the observed farmer practices reported here. These are then discussed in the light of the heterogeneity of the environment in which hill farming operates and the trade-offs that farmers make in their crop component to ensure system compatibility. This includes a reassessment of the role of fodder trees within the integrated crop and livestock system and their direct impact on crop cultivation, previously ignored in crop improvement. We then conclude by discussing the implications of these findings for future crop improvement programmes for hill maize specifically in Nepal and for crop improvement in integrated hill farming systems more generally.

Discrepancies between recommendations and practice

It is clear from the results that in several important respects farmers were not following recommendations for growing maize, resulting in a wide gulf between farmer practice and the research and extension effort that is designed to support them. Key departures from current recommendations included:

- incorporation of fodder trees, that compete with crops, on terrace risers;
- high initial seed rates coupled with reduction of plant population by thinning, resulting in a low population density at harvest;

- high compost and manure but low mineral fertilizer inputs;
- stripping lower maize leaves to reduce shading of intercropped millet; and
- low adoption rate of certified seed of new maize genotypes.

Each of these discrepancies between recommendations and farmer practice is discussed in the following sections.

Incorporation of fodder trees on crop terrace risers

Maize grain yield in close proximity to trees was on average from 11 to 47 % lower than that in the open at the three sites (Table 3), showing that trees that farmers are choosing to incorporate on their farms have a large impact on crop production. Terraces are typically 3 to 10 m wide, so some degree of shading is inevitable when there are trees on the terrace risers, and as maize and finger millet both have the C_4 pathway of carbon assimilation, their productivity is thereby limited. Results clearly showed lower maize grain and stover yields in close proximity to trees, likely to arise from both above and below ground competition for resources.

There are few comparable studies of maize production under trees in farm conditions but Joshi and Devkota (1996) recorded large reductions in maize yield under *Ficus auriculata* trees grown on research station terraces in the eastern mid-hills of Nepal. They reported 34 % lower grain yield of local maize under tree shade than in the open in one year and a 63 % reduction in yield of the new variety Manakamana-1 in the subsequent year. Very large yield reductions have also been reported on research stations in semi-arid Kenya, with regular and dense tree spacing. Maize yields were reduced by more than 50 % under a continuous *Grevillea robusta* canopy, with most of the yield reduction attributed to competition for water by comparison with much higher yields under shade net treatments (Lott *et al.*, 2000). Similarly, maize grain yield reductions of 50–70 % were reported between rows of *Melia volkensii*, *Senna spectabilis*, *Gliricidia sepium* and *Croton megalocarpus* and were strongly correlated with available soil moisture, again indicating predominance of below ground competition in the Kenyan setting (Odhiambo *et al.*, 1999). In the Nepalese mid-hills, the climate is more humid, with lower incident light levels, well below the light saturation point for maize (Tiwari *et al.*, 2002a), so it could be expected that overhead shade would have a proportionately larger impact on yield than in the semi-arid conditions in Kenya. This was confirmed experimentally in artificial shade experiments in the eastern mid-hills where shade netting reduced light transmission by 40 %, and yield by 43 % (Tiwari, 2001), indicating proportionality of reduction in light and grain yield.

While there has been mounting evidence of the increasing importance of fodder trees on crop terrace risers in the mid-hills of Nepal, as farmers have responded to decreasing access to forest, the impact of these trees has not been considered in the development of extension recommendations for hill maize. The increasing importance of fodder from farm grown as opposed to forest trees has been documented in the forest and livestock sectors (Carter and Gilmour, 1989) along with both local and scientific confirmation of its nutritive value for livestock (Thapa *et al.*, 1997; Walker *et al.*, 1999; Thorne *et al.*, 1999). There have also been reports of both local and scientific evaluation of significant competitive effects of these trees on crops (Thapa *et al.*, 1995; Joshi and Devkota, 1996). Despite this, trees are not mentioned in the most recent characterization of maize agro-ecologies in Nepal produced by the Nepal Agricultural Research Council and International Maize and Wheat Improvement Center as part of the Hill Maize Research Programme (Paudyal *et al.*, 2001). The importance of livestock within integrated farming systems in the hills is acknowledged, but only in respect of their consumption of significant quantities of maize grain and provision of manure and draught power. Use of forest resources to supplement compost made from livestock manure is mentioned but the implications of growing fodder on farmland is not considered. The present findings underline the importance of trees as a trade-off that farmers make between fodder supply and crop yield.

Seed rate and management of population density

Farmers used high seed rates, up to three times more than the national recommendation, partly to mitigate against various risks, but principally to allow for thinning young maize plants to use as livestock fodder. This results in a plant population profile that is higher than recommended at the beginning of the season but lower than recommended at harvest. Other on-farm studies carried out in the eastern and western mid-hills of Nepal corroborate these findings, indicating a great variation in plant population count at emergence and in other subsequent counts until harvesting (Gurung and Rijal, 1993; Khadka *et al.*, 1993; Subedi and Dhital, 1997; Paudyal *et al.*, 2001). In an on-station study, Adhikari and Sharma (1992) found that a plant population of 66 000 ha^{-1} gave the highest grain yield and a field density of at least 53 000 ha^{-1} after thinning was recommended. They further reported that grain yield was significantly lower when maize plant population was 38 000 ha^{-1} and Subedi (1994) reported that grain yield increased linearly with increasing plant densities from 33 000 to 73 000 ha^{-1}. These findings suggest that the population densities of 27 700 to 41 300 ha^{-1} (Figure 1) at harvest, used by farmers in the present study, are likely to result in lower grain yields than could be achieved. This research on optimum plant population densities for Nepal was conducted under monocrop conditions, without any influence of trees, and hence may have little relevance to the mid-hills agro-forestry system with relay cropped finger millet that farmers actually practice.

The mean yields of maize at Patle, Marga and Fakchamara were 53, 60 and 85 % higher than the average of 1.71 t ha^{-1}, reported for the whole eastern mid-hill region in 1998 from national statistics (Paudyal *et al.*, 2001) but the present yields were derived from data sampled to compare shaded and open parts of terraces rather than to estimate mean yield, which will clearly be influenced by the proportion shaded. The measured yields may also be expected to be higher than average yields obtained by farmers because the requirement for a regular size and shape of measurement quadrat for comparing shaded and open locations meant that terrace edges were avoided and they had to be located on terraces of a sufficient size to accommodate the plot. As with incorporation of trees into farm systems, farmers are clearly trading off the green fodder that they obtain from young plants that they subsequently thin against final grain yield.

Interestingly, farmers used the same seed rate irrespective of shading but population at emergence was lower under shade than in the open (Figure 1). This indicates that shade reduces germination but that farmers are not compensating for this. Farmers in nearby Solma village have suggested that larger raindrops falling from tree leaves (locally called *tapkan*) cause increased splash erosion and surface capping of soil (Thapa *et al.*, 1995). This could be expected to inhibit emergence but soil may also be cooler and damper under shade, leading to a longer sowing to germination interval, with more opportunity for predation and rotting.

Soil fertility management

The major form of soil fertility management practiced by farmers was the addition of around 20 t ha^{-1} of composted farmyard manure (FYM). Mean rates per site ranged from 19 to 24 t ha^{-1}, with less applied at the site with a lower fodder tree density and fewer livestock. Fewer than 20 % of farmers used mineral fertilizer. In contrast, the national recommendations for maize are to apply N, P_2O_5 and K_2O at rates of 90, 40 and 40 kg ha^{-1} respectively but do not refer to compost or farmyard manure. Combining data on compost amounts and their nutrient content measured in the present study, suggest gross nutrient addition rates far higher than those recommended for mineral fertilizer but the release characteristics of the compost were not assessed and so nutrient supply to the crop could not be determined. Other research indicates considerable variability in farmer practice across the mid-hills. Vaidya and Gurung (1996) reported that maize was a heavily fertilized crop receiving on average 34.7 t ha^{-1} of composted farmyard manure in the western mid-hills, with only 18–19 % of farmers using mineral fertilizer while Rasali *et al.* (1995) also in the western mid-hills reported only 13 to 18 t ha^{-1} being applied to *bari* land. In their characterization of hill maize cultivation, Paudyal *et al.* (2001) cited 11 and 22 t ha^{-1} as average application rates for the eastern, and central and western, mid-hill regions respectively.

Mean application rates for locations, often quoted in agronomic studies, obscure differences within sites. In the present study, nutrient content of composted FYM varied but there was no correlation between this and the amount applied, and, maize grain yield was only weakly correlated with the amount of FYM applied at one out of the three field sites. Application rates were determined more by socio-economic factors, such as labour availability and field location rather than either the crop demand, or, the nutrient supply potential of the manure. Soil mineral N and OM contents measured in farmers' fields were low. Goldsmith (1981) reported that soils in the eastern hills are generally acidic, with low N and OM content, medium to high potassium and low to medium phosphorous. Farmers appear to have responded here to low OM content in soil by applying heavy doses of compost and they explicitly linked use of chemical fertilizer solely with soil hardening. This underlines the need for advice for farmers on plant nutrient management, involving combinations of organic and inorganic amendments that can be tailored to local circumstances rather than blanket recommendations for fertilizer application for particular crops.

Hill farmers have responded positively in recent participatory research on integrated plant nutrient management, where soil analyses and advice on additions were provided to them (Subedi and Sapkota, 2002). While it would be impractical to provide analytical services generally to farmers across Nepal, they already appear to have their own indicators for assessing soil and crop nutrient status that might be built upon. For example, other socio-economic conditioning factors aside, farmers in western Nepal apply soil amendments differentially according to locally defined soil classes (Joshi *et al.*, 2004) and across Nepal, their ranking of organic manure quality was found to correlate with nitrogen content (Tamang, 1992). Farmers are even aware that inclusion of certain tree fodders in livestock diets may affect manure quality (Thorne *et al.*, 1999), underlining the integrative nature of farmer decisions about trees, crops and livestock.

Leaf stripping

While relay intercropping of maize with finger millet is acknowledged as a widespread practice in the mid-hills (Paudyal *et al.*, 2001), agronomic recommendations are not tailored to take account of it. In contrast, farmers make specific provision for the millet, principally affecting the maize by removal of lower leaves to ease access when transplanting millet and to reduce shading of the millet. These findings contradict Subedi's (1996) assertion that farmers in the western hills practice leaf stripping solely because of their fodder value rather than to favour the millet. Leaf stripping was done as grain filling commenced, and so could affect maize productivity, but as the lower leaves that are removed are already heavily shaded this is unlikely to have had a major impact on maize yield, as has been confirmed experimentally (Subedi, 1996). As in the western hills, the farmers in the present study also valued stripped leaves as fodder, underlining once again the integrated nature of the farming system and the multifaceted decision making process surrounding apparently simple agronomic practices.

Use of new maize varieties

Only four new maize varieties, all open-pollinated, have been released for cultivation in the mid-hills in Nepal since 1960. These were Khumal Yellow in 1966, Manakamana-1 twenty years later in 1986 and then Makulu 2 and Ganesh 2 in 1989 (Paudyal *et al.*, 2001). There has been no maize variety specifically recommended for maize/millet intercropping (Subedi, 2002). Of the new varieties, only Manakamana-1 was being used by farmers in this study, but this was almost entirely farm-saved seed rather than purchased seed, so that the attributes of the crop were reported to be closer to local landraces rather than certified seed of Manakamana-1. This allows us to conclude that there was negligible adoption of new maize genotypes in the study areas, consistent with findings more generally in Nepal. While the area covered by new varieties in the eastern hills in the mid 1990s was estimated as 6 % of the total cropped area (Chemjong *et al.*, 1995), seed sale records reveal that the amount of new seed sold was sufficient to cover only 1 % of the maize area in 1998/99 (K. B. Koirala, personal communication).

New varieties have been centrally developed and tested in open grown conditions, without intercrops and with the use of recommended agronomic inputs. As is clear from the results of the present study, such conditions are not representative of hill farms. Farmers also use unexpected criteria in their phenotypic selection. For example, plant lodging remains a problem with local germplasm under tree shade (Table 3) and, given the lack of correlation between stem height and lodging, is more likely to be caused by weakness of stems combined with high position of ears, a common morphological feature of local maize varieties. Application of scientific rationale would result in selection for lower ear position to reduce the mechanical leverage on the base of the stem, in order to reduce lodging. However, high ear position is selected by farmers because it provides some protection from predation by jackals.

Farmers' comments about new varieties not performing well under shade and drought conditions, showing susceptibility to pests and diseases, and requiring high input levels, substantiates the view that the new varieties are not well adapted to the actual conditions on farms, where tree shade and competition for water with trees and intercrops often prevail and input usage is low. Furthermore, farmers consider that some post harvest traits, such as the taste of grain and the fodder quality of stover, were higher in local landraces than the new varieties. It is also clear from the results of this study that on-farm conditions are heterogeneous amongst and within farms in the mid-hill zone and so it is highly unlikely that one combination of traits, in one particular variety, will suit all conditions. The implications of this for crop improvement are clear: a larger range of germplasm needs to be tested on farm, by farmers, so that the best performing material under farm conditions that best meets farmers' objectives can be identified.

Recent progress with participatory varietal selection (Joshi and Witcombe, 1996) and breeding (Virk *et al.*, 2003) in rice in India and Nepal has led to identification and adoption (Witcombe *et al.*, 1999) of a range of new varieties contributing to higher productivity and agro-biodiversity (Witcombe *et al.*, 1996). The present results suggest that similar progress can be expected with maize, but as it is open-pollinated, prescreening germplasm for on-farm testing, based on sound knowledge of farm conditions and farmers' preferences, assumes greater importance (Witcombe *et al.*, 2003).

Implications for research and extension

The discrepancies between farmer practice and recommendations that have been identified here stem from the integrated and complex nature of the farming system. Despite a strong tradition of documenting farming systems in the mid-hill stations in Nepal (Gibbon and Schultz, 1989), mainstream research on the maize component has still been directed at maximizing grain yield rather than optimizing production from maize in the context of farmers' multiple objectives and uses of their crop terraces (Paudyal *et al.*, 2001). Requirements for livestock fodder, use of their manure and the integration of intercrops and fodder trees on terraces, while important to farmers, have not been adequately taken into account in research and extension. Furthermore, underlying variation in soils, aspect, altitude, access to resources and ethnicity acting on an already complex system create a vast heterogeneity of conditions within and amongst farms. This variability is particularly acute for hill maize. Micro-variability both within and between *bari* terraces, on which maize is grown, was greater than that on *khet* land with bunded terraces used for paddy rice (Fielding and Sherchan, 1999). The low level of adoption of centralized recommendations and germplasm developed for maize in the mid-hill region, or large agro-ecological domains within it, demonstrates that variation in farmer circumstances has rendered these of very limited applicability.

Recently, maintaining and harnessing cultural and biological diversity in mountain landscapes has emerged as an important development imperative (Partap and Sthapit, 1998). The diversity of tree species associated with the maize terraces in the present study represents a significant reservoir of biodiversty in itself as well as a productive resource (Thapa *et al.*, 1997). Increasing production through encouraging agrodiversity (Brookfield and Stocking, 1999), as opposed to farmers conforming to a narrow set of practices and plant germplasm, has led to more sustainable intensification of mountain farming systems in Thailand (Rerkasem *et al.*, 2002).

Given the level of heterogeneity of environment for hill maize in Nepal, it is not feasible to develop extension packages for ever more finely defined recommendation domains. Yield levels and trends do, however, indicate that there is considerable scope for improvements in maize yield while maintaining system compatibility. A feasible way of achieving this is to allow farmers to select and adapt new maize germplasm and other innovations from a set of options that are potentially relevant to them and for them to incorporate these within their systems. Facilitating this, however, would require decentralization of agricultural support services and means of tailoring extension advice on technology options to local circumstances.

Participatory varietal selection and breeding approaches are already available to address requirements for unified research and extension of locally relevant germplasm but require decentralization of seed supply and certification to be implemented. Crop husbandry innovations are more difficult to address because they are more complicated and less tangible. They require tools for selecting what agronomic options are locally relevant given the natural and socio-economic environment of particular farmers. Success with similar approaches to decision support in related fields indicates that this is possible. For example, knowledge-based systems tools for tailoring extension advice on tree fodder options to local conditions have already been developed for Nepal (Thorne *et al.*, 2000) and for selecting cover crops to improve soil fertility for smallholders in Ghana ('Leginc', Moss *et al.*, 2003). Decision support tools for soil and water conservation in mountain environments have been developed and applied at a range of scales ('WOCAT', Liniger and Schwilch, 2002).

CONCLUSIONS

Documenting farmer practice in relation to the agronomy of a major crop was a useful way of exploring constraints and opportunities for crop improvement through exploring discrepancies between recommendations and practice. The approach focussed on elicitation of farmers' explanations for their practices, revealing key trade-offs in their decision making amongst components of their complex and integrated farming system. Previous, centralized approaches to crop improvement have resulted in germplasm and agronomic recommendations that bear little relevance to actual and highly varied farmer circumstances. The coupling of knowledge-rich extension advice on locally relevant crop management options, with participatory selection of germplasm, is required to support farmer innovation. This in itself demands new thinking and skills amongst research and extension staff, and new institutional mechanisms and tools to facilitate their interaction with farmers. Nepal was the example used in this paper, but the conclusions are likely to be applicable in any highly heterogeneous environment, particularly foothills of mountain ranges.

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Implications of hill farmers' agronomic practices in Nepal for crop improvement in maize. T. P. Tiwari, R. M. Brook, F. Sinclair. Geography. 1 October 2004. SUMMARY An agro-ecological analysis of the maize component of an agroforestry system in the eastern mid-hills of Nepal was conducted in 1999. The aim of the study was to understand farmersâ€™ currentâ€¦ Expand. 43. Annex 1. participatory crop improvement for maize in the eastern mid-hills of nepal: overview and site description. Annex 2. local knowledge about maize cultivation in the eastern MID hills of nepal. Annex 3. agronomic characterisation of bari land crop terraces in nepal. Annex 4. physiological and agronomic response to shade of local and introduced maize genotypes in nepal.Â Farmers' knowledge was verified in agronomic and physiological characterisation of the environment in which maize is grown, including the climate, soil and farmer decisions that define the context in which the maize crop has to perform. Agronomic strategies that could help address these concerns include intensification of terraces using agro-ecological approaches along with introduction of light-weight, low-cost, and purchasable tools and affordable inputs that enhance productivity and reduce female drudgery. To package, deliver, and share these technologies with remote hillside communities, effective scaling up models are required.Â Nepal, for example, lies in 157th place out of 187 countries listed in the UNDP's Human Development Report with a Human Development Index of 0.463 (IFAD, 2015).Â In Nepal, 93% of farmers face some amount of terrace failure that requires an average of 14 days of labor per year for repair activities (Gerrard and Gardner, 2000).