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Nutrient Dynamics in Farming Systems of the Jhikhu Khola Watershed

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Abstract

Maintaining soil fertility is very important for subsistence farmers in the middle mountains of Nepal. They are under tremendous pressure to meet the growing demand for food. Farmers with access to markets have increased productivity by intensifying their farming. In the past ten years farmers in the case study area of the Jhikhu Khola have moved from two annual staple crop rotations (rice and wheat or maize) to triple annual crop rotations (rice, potatoes, tomatoes). This has, however, led to concerns about maintaining soil fertility. Urea, the dominant fertiliser in early agricultural intensification, has been largely replaced by diammonium phosphate. Analysis of soils in the study area in the mid-1990s found widespread deficiencies in nitrogen and phosphorus. Farmers have adjusted their inputs since then and by 2000 phosphorus inputs in intensive irrigated sites were exceeding crop requirements. In contrast nitrogen and potassium had become insufficient resulting in negative nutrient balances. The potassium deficiencies were surprising as many Nepali soils have a naturally high potassium content. In contrast, the study found that in 2000 intensive rainfed sites under double and triple rotations all had surpluses of nitrogen, phosphorous, and potassium. This has negative impacts on water quality and is resulting in eutrophication problems as well as unnecessary extra expense for farmers. The findings indicate that farmers are highly motivated and aware of soil fertility problems associated with intensification and are managing to address the problems themselves.

Background

The agricultural systems of the middle mountain watersheds of the Jhikhu Khola and the Yarsha Khola in east-central Nepal are characterised by small landholdings with typically less than one hectare of cropping land per household. They are intensively cultivated with high inputs of labour. To meet the growing demand for food by the rapidly increasing population (2.6% per year population growth) the cropping systems have become very intensive. In 1996 the population density in the Jhikhu Khola was 437 km^2 and in the Yarsha Khola 386 km^2. Annual crop rotations estimated by Hagen (1980) for rainfed areas in Nepal averaged 1.3 crops/year, Panth and Gautam (1987) reported 1.6 crops/year, and Riley (1991) reported averages of 2.0-2.5 crops/year. Surveys carried out in the Jhikhu Khola (Kennedy and Dunlop 1989, Wymann 1991) reported an average of 2.7 crops per year on irrigated lands (*khet*) and 2.5 crops per year for rainfed cropping lands (*bari*). In Yarsha Khola, cropping intensities have been reported as between 1.5 and 2.0 crops per year in rainfed lands and 2.0-2.5 crops per year in irrigated areas (Brown 1997).

Agricultural intensification has brought about significant changes in the traditional farming systems with a shift towards the cultivation of seasonal cash crops. This has led to shorter fallow periods and dependency on more inputs that are often difficult to maintain by subsistence farmers. This dependency on chemical fertilisers is increasing whilst the amount of farmyard manure-compost fertiliser has remained constant. Cash crop production in irrigated areas, where profit margins are high, receive most of the farmyard manure and compost.

The cultivation of the rainfed upland fields near homesteads has also undergone a shift away from traditional practices. These changes affect the long-term sustainability of upland farming systems as organic matter – the main ingredient for maintaining soil fertility – is being diverted to apply to the irrigated sites. These large changes that have taken place over the past 20 years indicate the great adaptability of farmers.

In summary, the increases in population pressure in the study watersheds has brought about agriculture intensification, the increased use of chemical fertilisers and pesticides to maintain productivity and soil fertility, and the more intensive use of common property resources.

Agricultural expansion onto marginal lands that may be more susceptible to erosion is not of great concern because in these two watersheds the forests have been handed over to local communities to manage and are not available for conversion. The associated forest user groups generally follow strict rules and regulations on how to manage and maintain their forests. There is little spare land available for expanding the area under cultivation. However, the demand for the natural resources of forests, grazing, and water is constantly increasing to supplement intensive agricultural production systems. The use of organic materials collected from community forests and applied to cultivated areas as nutrient inputs is leading to a decline in forest soil fertility. Spring and river water sources are being heavily exploited for domestic and irrigation uses while the use of groundwater for drinking is a recent phenomenon in the Jhikhu Khola. There are acute water shortages during pre-monsoon periods.

Soil Condition

Soil and soil fertility surveys were carried out in both watersheds to document soil fertility and to serve as a baseline against which changes could be documented between 1990 and 2000. The main factors considered as important in soil fertility maintenance are topography, land use, cropping intensity, soil types and management practices.

The following soil fertility surveys were carried out:

- a detailed survey of forest and agricultural land in the Dhulikhel headwater region of the Jhikhu Khola (Wymann 1991) over 136 forestry and shrub sites and 120 agricultural sites;
- a general soil survey in 1990 (Maharjan 1991) over the entire Jhikhu Khola watershed with 350 soil pits analysed for basic nutrients;
- a detailed survey of agricultural and grazing land in 1993/94 in the Jhikhu Khola, Bela-Bhimsenthan area with a stratified sampling design to isolate slope, aspect, elevation, soil type, and land use effects over 200 sites in irrigated and dry land agricultural fields and grazing lands;
- a detailed survey in the Jhikhu Khola on the influence of land use practices on soil fertility at 10 sites where soil type, climate and topography were held constant in forests and adjacent irrigated and dry land agriculture fields; and

- a survey of the Yarsha Khola in 1998 over 150 agricultural and 190 forest sites with the watershed divided into three elevation classes, three aspect classes, three geological types and the four land use classes of forest, grazing, irrigated agriculture and rainfed agriculture.

The results of these studies allowed a comparison of the overall soil fertility status in the two watersheds (Table 4.1). This shows that despite the lower population pressure and lower agriculture intensity in the Yarsha Khola, the overall problems were similar in the two watersheds. These soil problems were low pH, low carbon content, lack of available phosphorous, and low base cations. The shortage of available phosphorus appeared to be a key problem with more than 50% of surveyed soils having very high levels of phosphorus sorption (ability to fix phosphorus and make it unavailable for plants to absorb). In the mid-slopes of the Jhikhu Khola watershed there are large areas of red soils that in all cover 37% of the watershed's area. These soils have a very high absorption capacity and although irrigation reduces this by 20-25%, this still leaves them with high absorption phosphorous absorption. About 80% of soils in both watersheds have an undesirable pH of about 5. The extensive use of acidifying fertiliser, pine litter in compost, and acidic bedrock cause this. Exchangeable potassium appears to be in adequate supply since it is widely distributed in the parent rocks.

Table 4.1: **Comparison of soil fertility values in the Jhikhu (JK) and Yarsha Khola (YK) watersheds**

	% carbon		Soil pH		Available phosphorous (mg/kg)	
	JK	YK	JK	YK	JK	YK
Mean	1.0	1.4	4.65	4.75	16.5	4.8
Maximum	3.7	6.5	6.70	7.42	127.1	52.4
Minimum	0.1	0.1	3.97	3.59	1.4	0.1
Sample size	200	340	200	340	200	340

Source: Schreier and Shah 1999

Only a third of Jhikhu Khola samples had adequate levels of carbon compared to two thirds of Yarsha Khola samples. This is due to the greater cropping intensity in the Jhikhu Khola and the more intensive use of forests. However, because of the sampling design a large proportion of the sampled soils are from higher elevations in both watersheds. The cooler climates at higher elevations may be leading to significantly higher carbon levels with elevation. About 10% of the Yarsha Khola samples had adequate phosphorous levels compared with 45% of Jhikhu Khola samples. Overall only 20% of all samples from both watersheds had adequate pH and less than 10% were within the desirable range. There was no significant difference in the overall pH values between the two watersheds.

In the Jhikhu Khola watershed during the late 1980s and early 1990s, farmers began to apply large amounts of diammonium phosphate fertiliser (DAP) to counter phosphorous deficiency. These large applications (Westarp 2002) have resulted in high levels of available phosphorous in intensively managed irrigated and rainfed sites. However a new problem has arisen with serious potassium deficiencies in triple crop rotation systems in irrigated lowlands, especially in potato fields. The intensive cropping is also expected to lead to micronutrient deficiencies. However, early surveys have not found any zinc, manganese, or copper deficiencies.

Investigations into boron and molybdenum are being carried out. Potassium was initially not perceived to be a problem since most of the bedrock contains potassium rich minerals. However, potassium deficiencies were observed for the first time in 2000 in intensively used irrigated systems growing potatoes.

Soil acidification, inherently associated with high inputs of acid-causing fertilisers (urea and ammonium based fertilisers), and acid bedrock geology, is becoming a major problem in double and triple crop rotation systems in the Jhikhu Khola area. Chitrakar (1990), Sherchan and Baniya (1991), and Suwal et al. (1991), have noted that the most commonly used fertilisers, ammonium sulphate and urea, tend to acidify soils. This acidification has serious implications as it leads to the leaching out of base cations (calcium and magnesium) and the fixing of available phosphorus in the soil thus making it unavailable to plants. Low soil pH (<5.0) slows the rate of organic matter decomposition, and makes phosphorous unavailable and leads to aluminium toxicity and micronutrient deficiencies.

PARDYP has been working in the Jhikhu Khola watershed since 1996. The PARDYP study team investigated whether or not the incorporation of pine litter in compost was contributing to soil acidification. However, earlier PARDYP experiments showed that that acidification is a slow process and different soils respond differently. In general this is a long-term problem as seen by researchers whilst farmers tend not to see it as a serious problem because it is not affecting their yields yet.

The surveys found poor overall soil fertility irrespective of land use, soil type, parent material, and management practice. In terms of land use, irrigated lowland fields had the best fertility followed by rainfed upland terraces, grazing lands, and lastly forests. This pattern was consistent regardless of soil type on red and other soils. The very poor status of forest soils indicates that long-term sustainability for productive use and management may be being jeopardised. This is likely the result of their natural low fertility and the continuous removal of litter and biomass.

Chemical Fertilisers

The use of mineral fertilisers has increased rapidly since they were first introduced in to Nepal in 1965. Their imbalanced use is known to lead to the problems of soil acidity and micronutrient deficiencies. This trend has not been accompanied by the replacement of organic matter. Farmers and researchers know that soil fertility status cannot be maintained in the medium to long term without replacing organic matter (Pandey et al. 1995, Joshi et al. 1996, Sherchan et al. 1999). Farmers have noticed that the continuous application of mineral fertilisers without adequate organic matter inputs leads to yield reduction, and deterioration in soil structure that makes it difficult to work. The above studies from other parts of Nepal have also reported deficiencies of micronutrients, notably boron, and soil acidification problems. But the literature is limited and more research is needed.

Compost Nutrient Content

Before the introduction of chemical fertilisers, compost used to be the main means of maintaining soil fertility in Nepali agriculture. Compost is usually a mixture of farmyard manure, household waste, forest litter, and other organic materials. Pine litter used as bedding material for animals is more acidic than broadleaf litter. The Swiss Agency for Development and Cooperation's Sustainable Soil Management Project (SSMP) is running an organic matter management programme throughout Nepal. It has resulted in innovations to improve the nutrient quality of farm compost. Compost nutrient content and quality vary widely across Nepal's middle mountains. The average values for the Jhikhu Khola are higher than in the other middle mountain sites given in Table 4.2. It is important to note that the moisture content of compost prior to transport is about 40-60%, but is only 25% once it reaches the fields (SSMP 2001).

Table 4.2: **Nutrient content of compost from Jhikhu Khola and comparable sites in Nepal**

Location	% N	% P	% K	Reference
Jhikhu Khola	1.93±0.41 (n=6)	0.56±0.13 (n=6)	2.15±0.27 (n=6)	Brown, pers. comm. 2001
Lumle (western Nepal)	0.6	0.06	0.6	Suwal et al.1991
Average: Jhikhu Khola + Lumle	1.27	0.31	1.38	
Middle mountain (MM) mean	0.83 (n=460)	0.72 (n=42)	2.26 (n=42)	SSMP 2001
MM range:	0.1 – 2.47	0.22 – 1.41	1.31 – 3.96	
Kavre district mean: range:	 1.38 (n=4) 1.00 – 1.97	 1.51(n=4) 0.96 – 2.10	 2.98 (n=4) 2.67 – 3.24	Bhattarai et al. 2001

Farmers in the Jhikhu Khola complain that the amount of organic matter available per unit land has declined due to land use intensification, restrictions on gathering litter from community forests, shorter fallow periods, fodder shortages, and labour constraints. Organic matter traditionally applied to rainfed lands near homesteads is being diverted to the more intensively cultivated irrigated fields.

Crop Yields

The PARDYP Nepal study team has compared crop yields from irrigated and rainfed fields in the Jhikhu Khola with average national figures and figures from experimental plots associated with agriculture research stations in Nepal (Table 4.3). The 1994 data for Jhikhu Khola represents less intensive sites with one or two crops per year, whereas the 1995 and 2000 data represents reported yields for intensive sites that have three or more crops per year.

This data shows that reported yields from Jhikhu Khola are generally greater than the national average. Reported rice yields for Jhikhu Khola in 1994, 1995, and 2000 were greater than the mean national average. Rice yields from the intensively managed sites (represented by the 1995 and 2000 Jhikhu Khola figures) were significantly greater than less intensively managed sites measured in 1994. The data indicates that yields of the major cash crops potato and tomato grown under intensive irrigation have increased, and potato yields from irrigated fields are significantly higher than national or average rainfed yields. Monsoon maize grown on rainfed fields always yield more than pre-monsoon maize in irrigated fields. Wheat yields have stagnated due to farmers' preferences for cash crops, but are still comparable to national averages. The intensification of production has resulted in larger external inputs, the greater uptake of soil nutrients by crops, and increased nutrient flows out of the system through crop harvesting.

Table 4.3: **Crop yields in Jhikhu Khola, Nepal , and the region**

Land type	Crop (season)	Year	No.	Jhikhu Khola yield (kg/ha) Mean ± std. dev.	National mean yield[a] (kg/ha)	Agric. research station mean yields (kg/ha) [range]
Irrigated	Rice	2000	26	5,786±1,252	2,600	3630[b]
		1995	26	5,223±1,797	2,391	[1179-5050][c]
		1994	26	3,222±1,046	2,124	
Irrigated	Potato (winter)	2000	26	23,993±6,667	na	na
		1995	19	22,660±11,219	9,854	
Rainfed	Potato (winter)	2000	13	10,368±6,866	8,593	na
		1995	9	9,447±7,094		
Irrigated	Maize (pre-monsoon)	2000	18	3,236±1,396	na	1560[d]
		1995	16	2540±485		
Rainfed	Maize (monsoon)	2000	20	3,943±1,755	1,701	2600[e]
		1995	18	3,850±2,068	1,645	2630[f]
		1994	32	4,171±1,875	1,650	3600[g]
Irrigated	Tomato (pre-monsoon)	2000	5	18,949±10,563	na	na
		1995	2	6919±890		
Rainfed	Tomato (pre-monsoon)	2000	9	12,449±6,625	na	na
		1995	6	14,513±7,459		
		1994	2	2,231±3,156		
Rainfed	Tomato (winter)	2000	5	5,252±2,153	na	na
Irrigated	Wheat (winter)	1995	6	2,062±683	1550	2310[d]
		1994	19	1,494±1,046	1470	[2000-3000][h]
Rainfed	Wheat (pre-monsoon)	2000	4	1,204±164	na	na
Rainfed	Wheat (winter)	1995	7	1,987±1,350	na	[1675-5984][b]
		1994	14	1,147±624		

Note 1: The agricultural resource stations are Lumle in central Nepal and Pakhribas in Eastern Nepal
Note 2: No national figures are available fo r yield of tomatoes
Source of Jhikhu Khola figures: Westarp, 2002. Source of other figures: a = FAO 2000; b = Subedi et al.1995; c = Sherchan et al.1999; d = Subedi and Gurung 1991 (average national yield 1981/1982); e = Vaidya and Gurung 1995; f = Tripathi 1997; g = Subedi and Dhital 1997; h = Subedi 1994.

Rainfed Farming Systems

Crops are grown throughout the middle mountains of the Hindu Kush-Himalayas on rainfed terraced hill slopes. The dominant such system in Nepal involves a fallow period followed by maize, or maize intercropped with a mixture of beans and millet during the monsoon and a winter crop of wheat, barley, or mustard (Figure 4.1). The intensification of cultivation with the introduction of high yielding varieties that need higher nutrient inputs has had a negative effect on local genetic legume resources. These were extensively intercropped with maize. However, the high levels of nitrogen in mineral fertilisers applied to high yielding varieties of crops and the lowering of soil pH has meant that many local varieties of legume are no longer grown, probably because soil pH has become too low for effective nodulation. Suitable promising varieties (bush beans) that are tolerant to high soil nitrogen levels have been introduced and tested with positive results. Millet is no longer cultivated in the Jhikhu Khola and wheat began to be replaced by barley from 1998/99 because of barley's better drought resistance, low nutrient requirement, and better straw palatability.

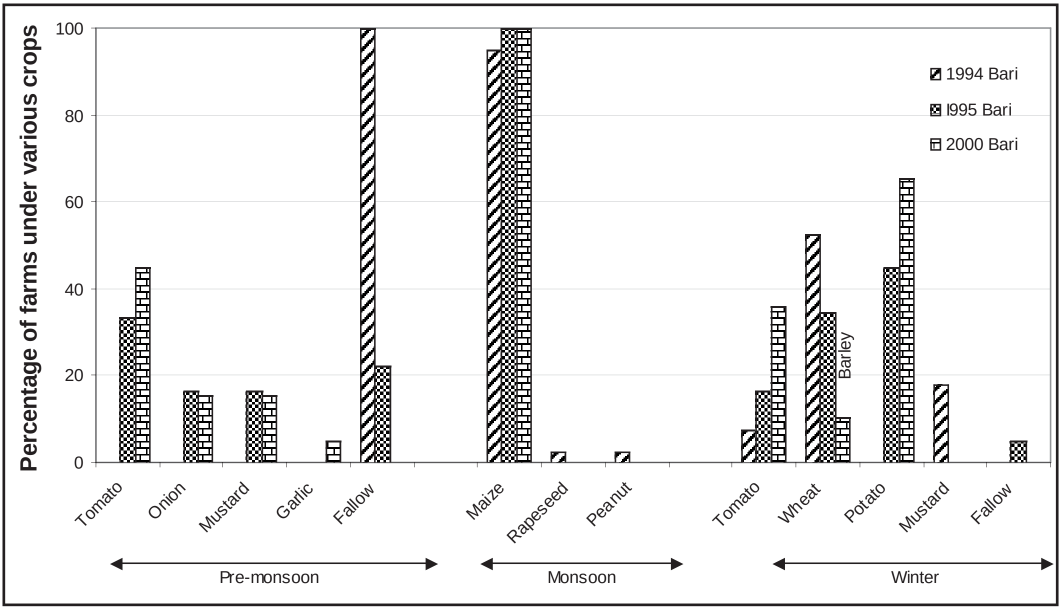

Figure 4.1: **Cropping rotations by season on rainfed fields in the Jhikhu Khola**
Source: modified from Westarp, 2002

Market oriented production has increased in intensively cultivated rainfed fields. Pre-monsoon and monsoon tomato, and monsoon potato cropping, have replaced some traditional crops. Tomato is grown instead of maize in areas with good access to market. Potato is now often intercropped with maize in late August. The area under tomato production has increased by about 50% while potato cultivation increased by about 15-20% between 1995 and 2000. The expansion of cash crop cultivation tends to be governed by the market prices of crops. Farmers prefer growing off-season cash crops as they give larger returns. Intensive rainfed systems continue to maintain a more traditional pattern of input management because of the limited availability of water.

A comparison of compost application in the Jhikhu Khola for 1995 and 2000 shows that it has remained constant at an average of 25-50 t/ha (Westarp 2002). This indicates that supplies from traditional sources (forests) have not altered (Tables 4.4 and 4.5). Overall the median annual application rate has increased by about 7t/ha due to farmers growing more cash crops in the winter and pre-monsoon periods.

The data shows that compost applications during the pre-monsoon and monsoon seasons have remained constant between 1995 and 2000, while applications to winter crops increased by 13%. Traditionally farmers have not applied compost to winter crops, but have begun to do this as they realise the importance of organic matter for maintaining soil fertility. However, increases in fertiliser use and the acidic nature of the soil parent material could cause future declines in soil pH which would accelerate the leaching out of essential minerals.

Table 4.4: **Compost application on Jhikhu Khola rainfed crops in 1995**											
1995	**Farmers sampled**	**% applying inputs**	**Compost applied (t/ha)**		**N inputs (kg/ha)**		**P inputs (kg/ha)**		**K inputs (kg/ha)**		
			M	**R**	**M**	**R**	**M**	**R**	**M**	**R**	
Monsoon maize	18	89	14.7	0–32.4	140	0-308	15	0-33	126	0–278	
Winter total	18	67	9.8	0–14.7	93	0-140	10	0-15	84	0-126	
Potato	9	100	12.3	9.8–14.7	117	93-140	12	10-15	105	85-126	
Wheat	7	14	0	0–9.8	0	0-93	0	0-10	0	0-84	
Pre-monsoon total	14	79	4.6	0–14.7	30	0-140	3	0-15	27	0-126	
Tomato	6	100	12.3	0–14.7	117	0-140	12	0-15	105	0-126	
Annual			31.9	0–49.6	303	0-471	32	0-50	273	0-425	

Source: Westarp 2002 Abbreviations: M = median, R = range

Table 4.5: **Compost application on Jhikhu Khola rainfed crops in 2000**										
2000	**Farmers sampled**	**% applying Inputs**	**Compost applied (t/ha)**		**N input (kg/ha)**		**P input (kg/ha)**		**K input (kg/ha)**	
			M	**R**	**M**	**R**	**M**	**R**	**M**	**R**
Monsoon Maize	20	90	14.7	0–49.1	140	0-466	15	0-50	126	0-421
Winter total	20	80	14.7	0–24.6	140	0-233	15	0-25	126	0-210
Potato	13	100	14.7	0–24.6	140	0-233	15	0-25	126	0-210
Tomato	5	90	5.9	0–24.6	56	0-233	6	0-25	50	0-210
Pre-monsoon total	20	75	4.9	0–16.2	47	0-154	5	0-16	42	0-139
Tomato	9	100	14.7	3.4–16.2	140	33-154	15	3-16	126	29-139
Wheat	4	25	0	0–3.4	0	0-33	0	0-3	0	0-29
Annual			39.2	9.8–54.6	372	93-520	40	10-56	336	84-470

Source: Westarp 2002 Abbreviations: M = median, R = range

Annual fertiliser application rates for nitrogen (253-414 kg/ha) and phosphorous (43-96 kg/ha) doubled between 1995 and 2000 in the Jhikhu Khola, but the application of potassium was limited. The rainfed fields have significantly higher levels of exchangeable potassium and soils are not exhibiting reduced levels of percent base saturation (calcium and magnesium). Comparative field studies (Westarp 2002) suggest that soil nitrogen, phosphorous, and potassium increased between 1995 and 2000 due to high compost and chemical fertiliser inputs, comparatively lower cropping intensities, and two to three month fallow periods – strategies adopted by farmers to conserve soil fertility and increase production. Organic matter inputs into maize, the main monsoon crop on rainfed fields, is high and organic nutrient sources provide 52% of total nitrogen and 20% of the total phosphorous that is applied.

In 1995 and 2000 the main fertilisers used were found to be urea and DAP (Table 4.6). The variation in the use of potash and complex fertiliser (N 20: P 20: K 20) was limited, but urea inputs on tomato declined while DAP inputs increased from 1995 to 2000. Urea and DAP inputs on maize increased and the high inputs on potato remained the same in the two years as further expansion was limited by lack of irrigation water. In 1995 organic sources provided the bulk of nitrogen and phosphorous for maize and potato, while wheat received its nitrogen, phosphorous, and potassium inputs mostly from chemical sources (Table 4.5). The increase in fertiliser use by farmers corresponds to the 50% increase in the number of farmers growing cash crops.

Table 4.6: **Fertiliser use in Jhikhu Khola rainfed fields for 1995 and 2000**

2000	Crop	Range	Urea (kg/ha)		DAP (kg/ha)		Complex (kg/ha)		Potash (kg/ha)	
			1995	2000	1995	2000	1995	2000	1995	2000
Monsoon	Maize	Median	295	442	-	86	-	-	-	-
		Range	0-491	0-826	0-491	0-786	0-79	0-197	-	-
Winter	Potato	Median	236	236	236	236	-	-	-	-
		Range	59-983	79-491	0-983	0-983	0-334	0-983	-	0-236
	Tomato	Median		34		152		-		-
		Range		0-688		0-491		Na		-
	Wheat	Median	-		-		-			
		Range	0-147		0-983		0-49			
Pre-monsoon	Tomato	Median	381	157	214	353	-	-	-	-
		Range	0-688	0-491	0-983	0-491	0	-	-	0-393
	Wheat	Median				-		-	-	-
		Range				-		-	0-197	-

Source: Westarp 2002 Note: no ammonium phosphate applied in either year

Soil erosion

The erosion of topsoil from rainfed fields is a major problem that leads to soil fertility and productivity decline. Much of the soil nutrients lost by soil erosion from rainfed fields accumulates and enriches the irrigated land that usually lies below.

Long term erosion plot studies carried out by PARDYP and previous initiatives in the Jhikhu Khola watershed (1992-2002) indicate that 50-80% of annual total soil losses occur in the pre-monsoon season when vegetation cover is at a minimum. Annual erosion rates at these sites range from 1 to 42 t/ha with the lowest losses from grasslands and losses of between 2-20 t/ha from cultivated rainfed land. The soil loss from degraded sites is almost twice as much as from cultivated land. In the cultivated plots the ten heaviest rainfall events were responsible for 90% of total annual soil losses. On the degraded plots 60-70% of total soil losses occurred during only two or three rainfall events. These findings have large implications for the management and use of rainfed cropping land and degraded lands in the upper reaches of watersheds. Up to 75-90% of total annual nutrient losses, via washed out sediment, can occur where cultivation, fertiliser application, and weeding occurs just before heavy rainfall (Westarp 2002). Much of the sediment is redistributed within the system and 30-60% was found to be recaptured in lower terraces.

The average annual losses from the rainfed terracing study plots in Jhikhu Khola watershed is 25 kg N/ha, 5 kg P/ha and 13 kg Ca/ha. The losses of available phosphorous are small, but the losses of organic phosphorous could be higher where high intensity rainfall happens before it is incorporated into the soil. In general losses from forests and grasslands with full coverage are minimal whilst annual losses from degraded sites are about 34 kg N/ha and 13 kg Ca/ha (Brown 1997).

Runoff rates from upland degraded and rainfed agriculture sites vary significantly in the Jhikhu Khola watershed. In degraded land plots the average annual runoff is about 5000 m^3/ha – a loss of 21 t/ha/yr of soil. This is much more than from rainfed sites, which averaged runoff of 450 m^3/ha and lost 7 t/ha of soil (Table 4.7). The difference is due to the relatively flat surfaces of rainfed terraces, tillage practices, and weeding which increase soil infiltration capacity. Degraded sites (<10% vegetation cover) have compacted soils with surface capping and poor infiltration. The findings indicate that soil erosion is not a severe problem in farmer-managed upland terraced fields but degraded areas are vulnerable to large soil and nutrient losses. These degraded areas need to be rehabilitated to reduce soil loss and minimise the impact of sediments clogging downstream irrigation systems.

Table 4.7: **Annual runoff and soil loss from rainfed agriculture and degraded sites (1992-2002) in the Jhikhu Khola watershed**

	Agriculture		Degraded		Degraded treated	
	Runoff (m3/ha)	Soil loss (t/ha)	Runoff (m3/ha)	Soil loss (t/ha)	Runoff (m3/ha)	Soil loss (t/ha)
Max. range	232-2197	3-37	6739-7141	34-38	-	-
Mean max.	891	19	6940	36	4914	40.70
Median range	138-985	1-18	4488-5185	18-23	-	-
Mean median	450	7	4837	21	3848	12.74
Min range	49-899	0-18	4155-4447	6.4-5.9	-	-
Mean min.	281	3	4301	6	2997	0.96

Source: Nakarmi 2003

Most nutrient runoff from agricultural fields happens through the loss of nitrates and phosphates. Runoff nutrient losses on degraded sites are only from organic sources; but in agricultural upland sites they are mostly from chemical fertilisers and compost. These differences were documented by PARDYP's long-term erosion research studies (Table 4.8). Nutrient losses in runoff are becoming a serious problem and will become more so with the inevitable intensification of cultivation on upland sites. It could be reduced to tolerable limits by growing suitable grass species on terrace risers. These would control surface soil erosion and increase fodder biomass production to feed to livestock to give more manure and thus more compost for applying to fields.

Irrigated Farming Systems

Irrigated terraces are located on gently sloping or level ground. They are intensively cultivated and receive large amounts of organic matter and fertiliser. Application rates vary by season and crop type. The cropping patterns are shown in Figure 4.2. The shift from winter fallow to cash crop production has brought significant changes in the management of these lands.

Table 4.8: **Nutrient losses in runoff from rainfed agriculture and degraded sites in the Jhikhu Khola watershed**				
	Agriculture		**Degraded**	
	Nitrate mg/l	**Phosphate mg/l**	**Nitrate mg/l**	**Phosphate mg/l**
Maximum range	19.8-22.0	6.8-7.6	2.6-4.5	1.2
Mean maximum	21	7.2	3.6	1.2
Median range	6.6-6.8	3.5-5.5	0.3-0.4	0.1-0.2
Mean median	6.7	4.5	0.4	0.15
Minimum range	2.4-2.8	0.4-0.6	0	0
Mean minimum	2.6	0.5	0	0

Source: Nakarmi 2003

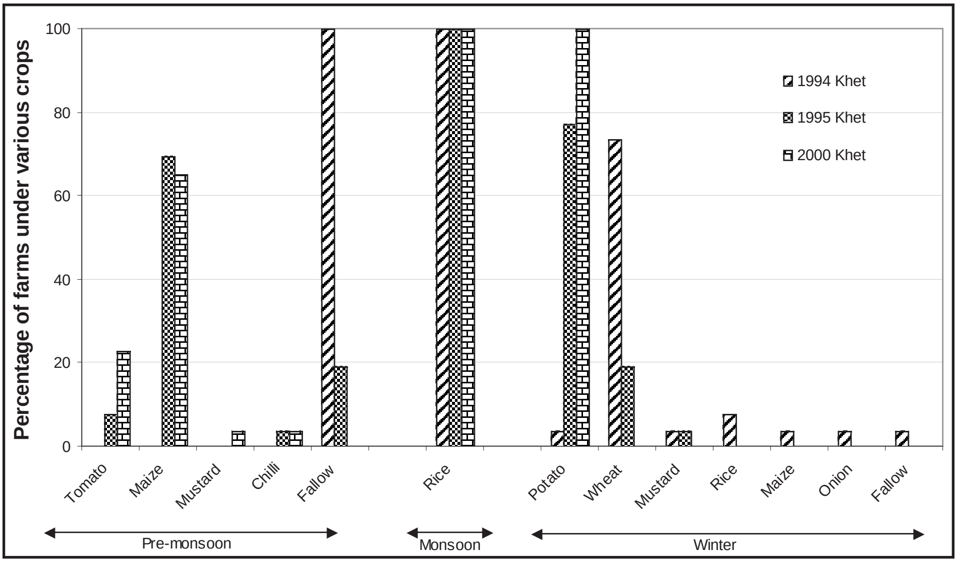

Figure 4.2: Cropping rotations by seasons on irrigated fields (khet)

Source: Modified after Westarp 2002

Comparative studies (Westarp 2002) found winter potatoes receiving the largest amount of organic matter and chemical fertiliser in both 1995 and 2000. A maximum application rate of 29 t/ha was recorded in 2000. Yearly average values reported by farmers for 1995 and 2000 were 12.2 and 14.7 t/ha. These figures are within the range documented by Gurung and Neupane in eastern Nepal (1991: 11 t/ha). Almost all of the farmers surveyed (96%) applied 11-14 t/ha of organic matter to their winter potatoes. The organic matter applied to pre-monsoon and monsoon crops was found to have declined by 11-15% between 1995 and 2000 (Tables 4.9 and 4.10). This reduction is due to the application of organic matter for the winter cultivation of potatoes by many farmers. No changes were recorded in organic matter addition to pre-monsoon crops, but applications have declined for monsoon rice between

1995 and 2000. The cultivation of the cash crops potato, tomato, and other vegetables has brought about a significant transfer of organic matter from less intensively managed rainfed and irrigated fields to intensive sites nearby roads with good access to markets.

Table 4.9: **Compost application on intensive irrigated fields, 1995**

1995	No. of farmers	% farmers applying inputs	Compost applied (t/ha)		N inputs (kg/ha)		P inputs (kg/ha)		K inputs (kg/ha)	
		%	M	R	M	R	M	R	M	R
Monsoon rice	26	8	0	0-27.0	0	0-256	0	0-27	0	0-231
Winter	26	77	9.83	0-29.5	93	0-280	10	0-30	42	0-125
Potato	19	19	11.3	0-29.5	107	0- 80	11	0-30	97	0-252
Wheat	6	17	0	0-9.8	0	0-93	0	0 -10	0	0- 84
Pre-monsoon Total	18	11	0	0-14.3	0	0-135	0	0-14	0	0-122
Annual	-	-	12.3	0-41.3	117	0-392	12	0-42	105	0-353

Source: Westarp 2002 Abbreviations: M = median, R = range

Table 4.10: **Compost application on intensive irrigated fields, 2000**

2000	No. of farmers	% applying inputs	Compost applied (t/ha)		N inputs (kg/ha)		P inputs (kg/ha)		K inputs (kg/ha)	
		%	M	R	M	R	M	R	M	R
Monsoon rice	26	8	0	0-4.9	0	0-47	0	0-5	0	0-42
Winter potato	26	96	14.7	0-29.5	140	0-280	15	0-30	126	0-252
Pre-monsoon total	26	0	0	-	0	-	0	-	0	-
Maize	18	0	0	-	0	-	0	-	0	-
Tomato	5	0	0	-	0	-	0	-	0	-
Annual	-	-	14.7	0-29.5	140	0-280	15	0-30	126	0-252

Source: Westarp 2002 Abbreviations: M = median, R = range

Chemical fertiliser use in irrigated fields varies by season and crop type. Winter cash crops receive the most fertiliser. The percentage of farmers fertilising winter and pre-monsoon cash crops has increased by nearly 25% between 1995 and 2000 (Table 4.11). Potato, the main cash crop received the greatest amount in both 1995 and 2000, but wheat, which is gradually being replaced by more profitable cash crops, received the least fertiliser. Chemical fertiliser inputs for dominant crops have increased from 351 to 436 kg N/ha, 83 to 240 Kg P/ha and 0 to 98 kg K/ha. Urea inputs have remained the same but large increases in DAP have

Table 4.11: **Fertiliser use in irrigated fields in 1995 and 2000**											
Crop		**Urea (kg/ha)**		**DAP (kg/ha)**		**Complex (kg/ha)**		**Potash (kg/ha)**		**Ammonium sulphate (kg/ha)**	
		1995	**2000**	**1995**	**2000**	**1995**	**2000**	**1995**	**2000**	**1995**	**2000**
Monsoon											
Rice	Median	157	143	nk	216	nk	–	–	–	nk	nk
	Range	0-393	0-491	0-236	0-590	0-491	–	–	–	0-98	0-118
Winter											
Potato	Median	138	197	nk	983	786	–	nk	197	nk	nk
	Range	0-295	0-688	0-983	256-1966	0-1966	–	0-138	0-491	0-491	0-197
Wheat	Median	–	–	nk	–	–	–	–	–	–	–
	Range	–	–	0-197	–	–	–	–	–	–	–
Pre-monsoon											
Maize	Median	98	157	nk	–	nk	–	–	–	–	–
	Range	0-393	0-491	0-295	–	0-236	–	–	–	–	–
Tomato	Median	nk	–	197	–	–	–	–	–	–	–
	Range	0-295	–	0-658	–	-	–	–	–	–	–

Source: Westarp 2002, nk = not known

happened. The dominant fertilisers applied in 1995 were urea and complex fertilisers, but by 2000 DAP had completely replaced complex fertilisers to overcome P deficiency. This has however resulted in over-fertilisation. Positive trends are noticeable in the number of farmers applying potash to potato (4% in 1995 and 81% in 2000). The rise in potash use is likely linked to promotion by extension services; reduction in yields, and enhanced farmer knowledge in trying to balance nutrient requirements for potatoes.

Farmers have responded to intensification by increasing inputs to maintain yield. Complex fertiliser (N.20:P.20: K.20) and ammonium sulphate are gradually being replaced by urea and DAP on the surveyed irrigated fields. This significant rise in fertiliser use justifies concerns about soil acidification. The increased use of organic matter could buffer the acidification of soils but it is difficult for farmers to get hold of more organic matter for composting.

Nutrient Budgets

The nutrient budget for crop rotation systems in irrigated and rainfed sites was assessed by looking at the findings of previous studies. The intensification of cropping in parts of the Jhikhu Khola watershed has led to potassium deficiencies, particularly in soils in irrigated fields where levels were previously adequate. In these fields about 6 kg N/ha, 1 kg P/ha and 13 kg K/ha comes from irrigation water. The flooding of rice fields provides an additional 15 kg N/ha/yr from biological nitrogen fixation (Brown 1997). The high input of potassium is attributed to the dominance of illite and micaceous clay minerals in the soils and bedrock of the area. Winter potatoes are irrigated about seven times in each season. This provides around 1.4 kg N/ha, 0.3 kg P/ha, and 6.5 kg K/ha (Schreier et al. 1994). The annual nutrient enrichment via suspended sediment in irrigation water in rice fields is around 1 kg P/ha, 2 kg K/ha and 28 kg Ca/ha (Shah and Schreier 1995).

Irrigated crops

The main cropping rotation system for irrigated lands in 2000 was monsoon rice-winter potato-pre monsoon maize – a rotation that remains common in 2003. In 1994 the most common rotation was monsoon rice-winter wheat-pre monsoon fallow. The new three crop rotation demands higher inputs. Consequently nitrogen input has increased from about 100 kg to almost 400 kg/ha/yr. Phosporous use has increased almost fourfold rising from 60 to nearly 240 kg/ha/yr. Intensive farms have a surplus of nearly 120 kg P/ha due to high inputs of DAP for potatoes. Potassium use has increased from 60 to 450 kg/ha/yr as a result of moving over to potato production and cultivating three crops per year (2000). However, even with these increased inputs there is about a 200 kg/ha/yr deficit of potassium on intensive sites. Sanchez (1976) documented comparable uptake values of 342 kg/ha/yr for rice-potato-wheat rotations.

In triple crop rotation systems overall N and K balances have been found to be negative but P shows significant surpluses. The P surplus is due to the heavy application of DAP for potato cultivation and other crops. But potato has the largest negative K budget followed by rice and maize (Table 4.12). Under less intensive management systems overall nutrients have been balanced.

Table 4.12: **Median nutrient balance for irrigated crops**

Cropping system	Crop	N balance (kg/ha/yr)	P balance (kg/ha/yr)	K balance (kg/ha/yr)
Intensive (2000)	Rice (n=26)	-79	+88	-51
	Potato (n=26)	+13	+19	-118
	Maize (n=18)	-8	+7	-16
Less intensive (1994)	Rice (n=26)	+15	+11	-27
	Wheat (n=19)	-5	+1	+6

Source: Westarp, 2002

Rainfed crops

The more intensive cropping of rainfed lands has had a positive effect on the overall nitrogen, phosphorous and potassium budgets of soils. In 1994, 50% of all farms examined showed negative nitrogen balances, 12% had negative phosphorous balances, and 72% had negative potassium balances. By 2000 only 30% of the intensive rainfed sites had negative potassium balances (Table 4.13). These positive trends are due to increased fertiliser application. However, despite these higher inputs, yields have not increased much and the yields of rainfed potatoes remain significantly lower than those in irrigated fields. Maize yields have become higher due to the introduction of new monsoon varieties.

Table 4.13: **Median nutrient balance for rainfed cropping**

Cropping system	Crop	N budget (kg/ha/yr)	P budget (kg/ha/yr)	K budget (kg/ha/yr)
Intensive (2000)	Maize (n=20)	33	2	-12
"	Potato (n=13)	119	31	6
"	Tomato (n=14)	116	40	61
Less intensive (1994)	Maize (n=31)	-84	-3	-68
"	Wheat (n=14)	10	3	9

Source: Westarp, 2002

The dominant cropping rotation of maize with wheat/mustard fallow in 1994 had been replaced in 2000 by maize-potato-tomato. Fertiliser inputs have increased dramatically to 100-450 kg of N and 50-150 kg of P ha/yr. Potassium inputs come mostly from organic sources.

The increase in intensive rainfed cropping is due to the cultivation of cash crops; with potatoes and tomatoes needing high inputs of fertiliser and organic matter. For rainfed maize on the less intensive systems the nitrogen and potassium balance was found to be negative whilst in the more intensive system potassium deficits were small (Table 4.13).

Soil Fertility Dynamics

The greatly increased production of cash crops has led to an intensification of the farming systems studied and significant effects on the nutrient budget and soil nutrient pools of irrigated and rainfed crops. No changes were observed in soil pH between intensively and less-intensively farmed sites; but a slight decline was noted in irrigated fields and a slight increase in rainfed fields. This intensification has not led to more acid soils as the soils are already acidic with a pH of about 5 and it would probably need higher levels of acidic inputs to cause further declines. Also the calcium enriched irrigation water tends to buffer the effects of soil acidity in irrigated sites.

Substantial surpluses of phosphorous were noticed in intensive systems but exchangeable calcium, magnesium and the percentage base saturation were lower in comparison to less intensive sites. The field observations and study results do not support the notion that acidification is a widespread problem despite increased fertiliser use. The large amounts of compost applied by farmers also seem to be buffering soil acidity.

Carbon and nitrogen levels are significantly higher in irrigated fields than rainfed fields contrary to previous observations. This is believed to have occurred recently due to changes in the cropping patterns and the application of higher levels of inputs. The carbon and nitrogen levels in soils in rainfed and irrigated fields under three or four crop rotations per year are below desirable levels. The most significant findings of interest to both farmers and researchers is that potassium levels have dropped dramatically in intensively managed irrigated systems and phosphorous levels have increased in intensively managed irrigated and rainfed sites.

Soil erosion is not a major problem but nutrient losses in runoff from rainfed sites were found to be substantial. Farmers readily adopt new practices as land intensification increases. What seems to be happening is that as the deficiency of one nutrient is corrected another becomes deficient. The deficiencies in the macronutrients nitrogen, phosphorous and potassium have been addressed but deficiencies in calcium, magnesium, sulphur, and the micronutrients will likely become deficient if intensification increases. These nutrients will need to be evaluated in the future to maintain a balanced nutrient supply for long term sustainability.

Acknowledgements

This paper presents the research findings of PARDYP's long-term soil fertility studies in the Jhikhu and Yarsha Khola watersheds. These studies have been carried out in collaboration with the University of British Columbia. The support from PARDYP Nepal team members is highly appreciated, especially from Regional Coordinator Roger White for his valuable comments on this paper and Samma Shakya for help with putting it into a presentable format.

References

Bhattarai, S.; Maskey, S.L; Gami, S.K.; Shrestha, R.K. (2001) *Environmentally Friendly Integrated Plant Nutrient Management for Sustainable Agriculture in Nepal*. Brief report on On-farm Documentation on IPNM. Kathmandu: Soil Science Division, National Agriculture Research Council. Fertilizer Advisory, Development and Information Network for Asia and Pacific

Brown, S.J. (1997) *Soil Fertility, Nutrient Dynamics and Socio-economic Interactions in the Middle Mountains of Nepal*. PhD Thesis, British Columbia: University of British Columbia

Chitrakar, P.L. (1990) *Planning, Agriculture and Farmers; Strategy for Nepal*. Kathmandu: Kedar Pradhan Printing Support Ltd. and G.D. Chitrakar

FAO (2000) FAOSTAT Agriculture Statistics Database. Food and Agriculture Organization of the United Nations. http://apps.fao.org/page/collections?subset=agriculture (15 December 2001)

Gurung, G.B.; Neupane, R.K. (1991) *An Estimate of Use of Farmyard Manure (FYM) – Compost in Field Crops in the Koshi Hills*. PAC Technical Paper No. 23. Dhankuta, Nepal: Pakhribas Agricultural Centre

Hagen, R. (1980) *Nepal*. New Delhi: India: Oxford and IBH Publishers

Joshi, K.D., Sthapit, B.R.; Vaidya, A.K. (1996) 'Indigenous Methods of Maintaining Soil Fertility and Constraints to Increasing Productivity in Mountain Farming Systems'. In Joshi, K.D.; Vaidya, A.L.; Tripathi, B.P.; Pound, B. (eds.), *Formulating a Strategy for Soil Fertility Research in the Hills of Nepal*, pp 20-29. Lumle Agricultural Research Centre, Pokhara, Nepal and Natural Resources Institute, Chatham Maritime, UK

Kennedy, G.; Dunlop, C.C. (1989) *A study of Farming Household Systems in Panchkal Panchayat, Nepal*. Report to the International Development Research Centre, Ottawa, Canada

Maharjan, P.L. (1991) 'The Soil Survey of the Jhikhu Khola Watershed Area'. In Shah, P.B.; Schreier, H.; Brown, S.; Riley, K. (eds.) *Soil Fertility and Erosion Issues in the Middle Mountains of Nepal*, pp 195-207. International Development Research Centre, Ottawa

Nakarmi, G. (2003) *Synthesis of Long Term Soil Erosion Plot Studies*. People and Resource Dynamics Project, ICIMOD, Nepal (unpublished)

Pandey, S.P.; Tamang, D.B.; Baidya, S.N. (1995) 'Soil Fertility Management and Agricultural Production Issues with Reference to the Middle Mountain Regions of Nepal'. In Schreier, H.; Shah, P.B.; Brown, S. (eds), *Challenges in Mountain Resource Management in Nepal: Processes Trends and Dynamics in Middle Mountain Watersheds*. Workshop Proceedings, Kathmandu, Nepal, April 10-12 1995, pp 41-49. Kathmandu: ICIMOD

Panth, M.; Gautam, J. (1987) 'Mountain Farming Systems in Nepal'. In Riley, K.; Mateco, N.; Hawtin, G.; Yadav, R. (eds.), *Mountain Agriculture and Crop Genetic Resources*, pp 51-68. Oxford, New Delhi

Riley, K.W. (1991) 'Soil Fertility Maintenance for Sustainable Crop Production in the Mid Hills of Nepal'.. In Shah, P. B.; Schreier, H.; Brown, S.; Riley, K. (eds.) *Soil Fertility and Erosion issues in the Middle Mountains of Nepal*, pp 3-14. Ottawa: International Development Research Centre

Sanchez, P. (1976) *Properties and Management of Soils in the Tropics*. New York: John Wiley and Sons

Schreier, H.; Shah, P.B. (1999) 'Soil Fertility Status and Dynamics in the Jhikhu and Yarsha Khola Watersheds'. In *The People and Resource Dynamics Project: The First Three Years (1996-1999) Proceedings of a Workshop Held in Baoshan, Yunnan Province, China* (March 2-5, 1999), pp 281-299. Kathmandu: ICIMOD

Schreier, H.; Shah, P.B.; Lavkulich, L.M. (1995) 'Soil Acidification and its Impact on Nutrient Deficiency with Emphasis on Red Soils and Pine Litter Additions'. In Schreier, H.; Shah, P.B.; Brown, S. (eds.), *Challenges in Mountain Resource Management in Nepal: Processes, Trends and Dynamics in Middle Mountain Watersheds*. Workshop Proceedings, Kathmandu, Nepal April 10-12 1995, pp 183-192. Kathmandu: ICIMOD

Schreier, H.; Shah, P. B.; Lavkulich, L.M.; Brown, S. (1994) 'Maintaining Soil Fertility under Increasing Land Use Pressure in the Middle Mountains of Nepal'. *Soil Use and Management*, 10:137-142

Shah, P.B.; Schreier, H. (1995) 'Maintaining Soil Fertility in Agriculture and Forestry'. In Schreier, H.; Shah, P. B.; Brown, S.; Riley, K. (eds.), *Challenges in Mountain Resource Management in Nepal: Processes, Trends and Dynamics in Middle Mountain Watersheds*. Workshop Proceedings, Kathmandu, Nepal April 10-12 1995, pp 171-182. Kathmandu: ICIMOD

Sherchan, D.P.; Pilbeam, C.J.; Gregory, P.J. (1999) 'Response of Wheat-Rice and Maize/Millet Systems to Fertilizer and Manure Applications in the Mid-hills of Nepal'. In *Exploratory Agriculture* 35: 1-13

Sherchan, K.K.; Banyia, B.K. (1991) 'Crop Production and its Trend in Response to Soil and Nutrients'. In Shah, P.B.; Schreier, H.; Brown, S.; Riley, W.K. (eds.) *Soil Fertility and Erosion Issues in the Middle Mountains of Nepal*. Workshop Proceedings, Jhikhu Khola Watershed, Nepal, (April 2001) pp 50-60. Ottawa: International Development Centre

SSMP (2001) *Benchmark Sites Database from Collaborating Institutions of SSMP.* Lalitpur, Nepal: Sustainable Soil Management Programme

Subedi, K.D. (1994) *Determination of an Optimum Combination of Organic and Inorganic Fertilizer for Rainfed Wheat and Barley 1993/94*. LARC Working Paper 94/42. Kaski, Nepal: Lumle Agricultural Research Centre

Subedi, K.D.; Dhital, B.K. (1997) 'Plant Population Dynamics of Maize under Farmers' Management in the Western Hills of Nepal'. In *Experimental Agriculture*, 33: 189-195

Subedi, K.D.; Gurung, G. (1991) *Soil Fertility Thrust Towards Sustainable Agriculture: Experiences of Lumle Regional Agricultural Research Centre*. Technical Paper 4/91: p 27

Subedi, K.D.; Rana, R.B.; Gurung, T.B.; GC, Y. D. (1995) *Assessment of Major Yield Limiting Factors of Normal Season Rice and Soil Fertility Research on Rice Under Low Hill Intensive Cropping Systems*. Kaski, Nepal: Lumle Agricultural Research Centre

Suwal, M.; Subedi, K.; Gurung, G. (1991) 'Soil Fertility Thrust Towards Sustainable Agriculture: Experiences of Lumle Regional Agricultural Research Centre'. In Shah, P.B.; Schreier, H.; Brown, S.; Riley, K. (eds.), *Soil Fertility and Erosion Issues in the Middle Mountains of Nepal*. Workshop Proceedings, Jhikhu Khola Watershed, 22-25 April 2001, pp 61-82. Ottawa: International Development Research Centre

Tripathi, B.P. (1997) *Investigation of Soil Fertility Management under Maize at LARC and its Extension Command Area: A Review*. LARC Review Paper 97/1. Kaski, Nepal: Lumle Agricultural Research Centre

Vaidya, A.; Gurung, H.B. (1995) *Yield Estimation and Farm Management Study of Wheat in the Extension Command Area (1991/92-1992/93)*. LARC Working Paper No. 95/23. Kaski, Nepal: Lumle Agricultural Research Centre

Westarp, S. (2002) *Agricultural Intensification, Soil Fertility Dynamics, and Low-cost Drip Irrigation in the Middle Mountains of Nepal*. MSc Thesis, Faculty of Agricultural Sciences, University of British Columbia

Wymann, S. (1991) *Landutzungsintensivierung und Bodenfruchtbarkeit in Nepalischen Hugelgebiet, Diplom Projekt*. Institute of Geography, University of Berne, Switzerland