# Soil Fertility Status and Dynamics in the Jhikhu and Yarsha Khola Watersheds

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## Abstract

The soil fertility status in two different watersheds in the middle mountains region of Nepal was compared. The results showed that despite lower population pressure and reduced agricultural intensity in one watershed, the overall problems were the same: low pH, low carbon content, lack of available P, and low base cations. The lack of available phosphorus appears to be a key problem and, as shown in laboratory experiments, more than 50 per cent of the soils had very high levels of phosphorus sorption. The red soils had a particularly high absorption capacity and although irrigating red soils reduces the sorption by 20-25 per cent, the soils remained in the high absorption category. The fact that about 80 per cent of all soils in both watersheds have an undesirable pH (<5.0) contributes to the problem. The soils in the region are naturally acidic as a result of the dominance of acidic bedrock, but the extensive use of acid generating fertilisers and of pine litter in compost are contributing to the acid problem. A pine litter experiment showed that acidification from pine litter is a slow process and that different soils respond differently. It took 18 months of continuing litter addition (1kg/$m^2$ every 6 months) before a significant pH drop could be identified.

## Introduction

For quite some time, concern has been expressed that the soil fertility in the middle mountains of Nepal is declining as a result of agricultural intensification, insufficient inputs into the cropping system, and excessive use of biomass from the forests. As pointed out by Schreier *et al.* (1994, 1995) the inherent geology gives rise to soils that are generally acidic and have low nutrient content. Furthermore, the lack of sufficient manure, inadequate access to fertilisers, and the increase in crop rotations, mean that soil fertility is not being sustained. The problems of low pH, low carbon content, deficiency of available P, and lack of base cations are widespread in the Jhikhu Khola watershed and questions have been raised as to whether these conditions are representative of the soil fertility status in the middle mountain region as a whole. At the same time, strategies are being developed to suggest how the soil fertility status can best be improved in the region (NARC 1997). Three experiments have been carried out to address these questions. A new soil fertility survey was started in the Yarsha Khola watershed, a laboratory study was carried out to determine phosphorus dynamics in red and non-red soils, and a selective land use study was started to determine if the extensive use of pine needles is acidifying agricultural soils.

The soil fertility survey in the Yarsha Khola watershed was carried out to determine the overall fertility status in a watershed that has a slightly higher elevation range, has less intensive crop rotations, and is located in a more remote setting than the Jhikhu Khola watershed. The survey was also intended to help determine whether the same factors (elevation, aspect, slope, and land use) influence soil fertility distribution as found in the Jhikhu Khola watershed (Schreier *et al.* 1995).

Phosphorus has been identified as one of the critical nutrients in the Jhikhu Khola watershed. As a result of the low soil pH and the lack of organic matter, P-availability appears to be the most limiting nutrient in agriculture, and a better understanding of P-dynamics is needed in order to be able to recommend steps to improve the P status in the soils. Red soils are of particular concern because many have pH values less than 4.3, and below this value Al and Fe solubility increase rapidly. With Fe and Al in the soluble form, Al-toxicity becomes a concern, and the problems are compounded by the fact that any available P will react with Fe and Al to form insoluble phosphates, thus depriving the plants of available P.

For many years the government of Nepal established chir pine plantations as the first phase of afforestation. The idea was to use native species that are easy to germinate in a nursery, that resist moisture deficiency, and that survive poor soil conditions once transplanted into degraded sites. The survival rate of these plantations was very good because the trees are not much favoured by the local people. They provide no fodder and the firewood is not very desirable because of the sparks generated in open fires. The pine will eventually provide timber, and it was anticipated that once the plantations were established secondary forest cover would take over. Unfortunately, the demand for fodder is so high that without restrictions much of the palatable understorey is used. The majority of these pine plantations are now 20-25 years old, and because of the removal of the understorey cover they provide only limited protection against soil erosion. As shown by Shrestha and Brown (1995) and Schreier *et al.* (1995, 1999), the forests in the Jhikhu Khola watershed are now dominated by chir pine as a result of the extensive forest rehabilitation programme in the 1980s. Because of the scarcity of organic matter in agriculture, it has long been the practice to collect forest litter during the dry season for animal bedding and subsequently incorporate it into the agricultural system. Since the forests have become progressively dominated by pine, the proportion of pine litter in the collection of forest material has increased. Although we have long been concerned about the effect of pine litter in acidifying soils, no scientific data has been available to show whether this is a legitimate concern under the Nepali agricultural conditions.

As a result of the dominance of quartzite, sandstones, and siltstones in the watershed, and the dominant use of acid producing fertilisers (ammonium sulfate and urea), the soils in the Jhikhu Khola watershed are now in a pH range that is well below the levels considered optimal for agricultural production. The question of whether the addition of pine litter is contributing further to the acidification process of the soil under these management practices in Nepal has not yet been addressed in any depth. As a result, a long-term experiment was set up to document the potential processes.

## Methods

### *Soil Fertility Survey*

A new soil fertility survey was conducted in the 5000 ha Yarsha Khola watershed. The basin was divided into 3 elevation classes, 2 aspect classes, 3 different geological units, and 4 land use classes. Based on this 3x2x3x4 matrix, a total of 72 unique soil/land use polygons were identified and an attempt was made to sample up to 10 sites for each combination of factors. Some 34 combinations of classes were actually found to be present in the watershed and 340 soil samples (150 from agricultural sites and 190 from forest and rangeland sites) were collected for a comprehensive soil fertility analysis. At the time of sampling, 150 farm households and representatives from 20 forest user groups were interviewed (short survey) and pertinent data were collected on crop production, input variables, and forest and fodder use. A more detailed PRA survey was undertaken with 75 individual households and this data will be used to make detailed nutrient budgets and for a socioeconomic analysis. The soil fertility conditions were determined in the laboratory using the standard soil analysis methods described by Page (1982). A comparison was then made with the extensive data set available from the Jhikhu Khola watershed.

### *Soil Phosphorus Experiments*

Laboratory experiments were conducted to determine the key factors that are responsible for the low availability of P in the soils. They included a P-sorption experiment on red and non-red soils originating from irrigated and non-irrigated land. Fifty-nine samples were used in this subset; they were saturated with increasing P concentrations and Bray-P extractions were then carried out to determine the sorption isotherm. The results of the sorption capacity of the soils were then applied to the Bela sub-watershed (Jhikhu Khola Watershed) to determine how much of the watershed area would benefit most from the use of additional phosphorus fertiliser. Soils with low P-sorption capacity will make more of the applied phosphorus available to crops than will soils with high P-sorption capacity (details of the methods in Schreier *et al.* 1999).

### *Pine Litter Experiments*

The question of whether pine litter addition is speeding up the acidification process was investigated in a long-term plot experiment on red and non-red soils. A series of 12 plots (50x50 cm in size) were replicated for each of the two soil types—red soils originating from phyllitic parent materials and brown soils from quartzitic materials. Soil samples were collected before pine litter addition. After this 1 kg/m$^2$ of dry pine litter was incorporated into the soil in each plot, and the same amount added again at intervals of six months to selected plots as shown in Table 98. The soils of all 12 plot segments were analysed before the experiment started and six months after each addition of pine litter. The soils underneath the added pine litter were sampled in a destructive manner and analysed for pH, exchangeable cations, carbon, and available phosphorus (Bray-1) using standard procedures as described by Page *et al.* (1982).

Table 98: **Plot Design for Pine Litter – Acidification Experiment**

| | | | | | |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 7 | 8 | 9 | 10 | 11 | 12 |

| Addition of pine litter every 6 months @ 1 kg/m² | | | | | | |
|---|---|---|---|---|---|---|
| Plot No. | Time | Time | Time | Time | Time | Time |
| 1 + 7 | 1kg, Apr-96 | | | | | |
| 2 + 8 | 1kg, Apr-96 | 1kg, Oct-96 | | | | |
| 3 + 9 | 1kg, Apr-96 | 1kg, Oct-96 | 1kg, Apr-97 | | | |
| 4 + 10 | 1kg, Apr-96 | 1kg, Oct-96 | 1kg, Apr-97 | 1kg, Oct-97 | | |
| 5 + 11 | 1kg, Apr-96 | 1kg, Oct-96 | 1kg, Apr-97 | 1kg, Oct-97 | 1kg, Apr-98 | |
| 6 + 12 | 1kg, Apr-96 | 1kg, Oct-96 | 1kg, Apr-97 | 1kg, Oct-97 | 1kg, Apr-98 | 1kg, Oct-98 |

## Results

### *Comparison of Soil Fertility Status in the Yarsha and Jhikhu Khola Watersheds*

The problems of low pH, low carbon content, and deficiency of available P are widespread in the Jhikhu Khola watershed (JKW) and have been well documented by Schreier *et al.* (1994), Shah and Schreier (1995), and Brown and Schreier (this volume). With the partial completion of the Yarsha Khola watershed (YKW) soil fertility survey, it is now possible to compare the two watersheds.

The maximum, minimum, and mean values for various soil fertility factors in the two watersheds are shown in Table 99. The results show that:

- the percentage soil carbon is significantly higher in the YKW,
- the available phosphorus (Bray-1) is significantly lower in the YKW,
- the pH values are very similar in both areas.

To express the adequacy of the soil fertility better we set two tolerance thresholds, a conservative and a more lenient threshold. A one per cent soil carbon level is considered

Table 99: **Comparison of Soil Fertility Values in the Jhikhu and Yarsha Khola Watersheds**

| | % C | | pH | | Avail. P mg/kg | |
|---|---|---|---|---|---|---|
| | JKW | YKW | JKW | YKW | JKW | YKW |
| mean | 1.0 | 1.4 | 4.65 | 4.75 | 16.5 | 4.8 |
| maximum | 0.1 | 0.1 | 3.97 | 3.59 | 1.4 | 0.1 |
| minimum | 3.7 | 6.5 | 6.70 | 7.42 | 127.1 | 52.4 |
| n | 200 | 340 | 200 | 340 | 200 | 340 |

adequate in these Nepalese environments and a 1.5 per cent level is desirable. Similarly, a pH level of 5 is adequate and a level of 5.5 is desirable, and an available P level of 12 mg/kg is adequate and 15 mg/kg desirable. Figure 108 shows the percentage of the soil samples from the two areas with values above these threshold values.

Only about one third of all samples in the JKW had adequate percentage C levels compared with two thirds of the YKW samples (Figure 108a). This can be explained at least partially by the elevation and climate factors. Soil carbon tends to increase with elevation since temperatures become cooler and decomposition is slower, an effect noted previously by Wymann (1989) within the Jhikhu Khola watershed. Other factors that influence the carbon pool are:

- higher population density resulting in more intensive use of forests and less availability of organic litter;
- more use of fertilisers because of the introduction of cash crops; and

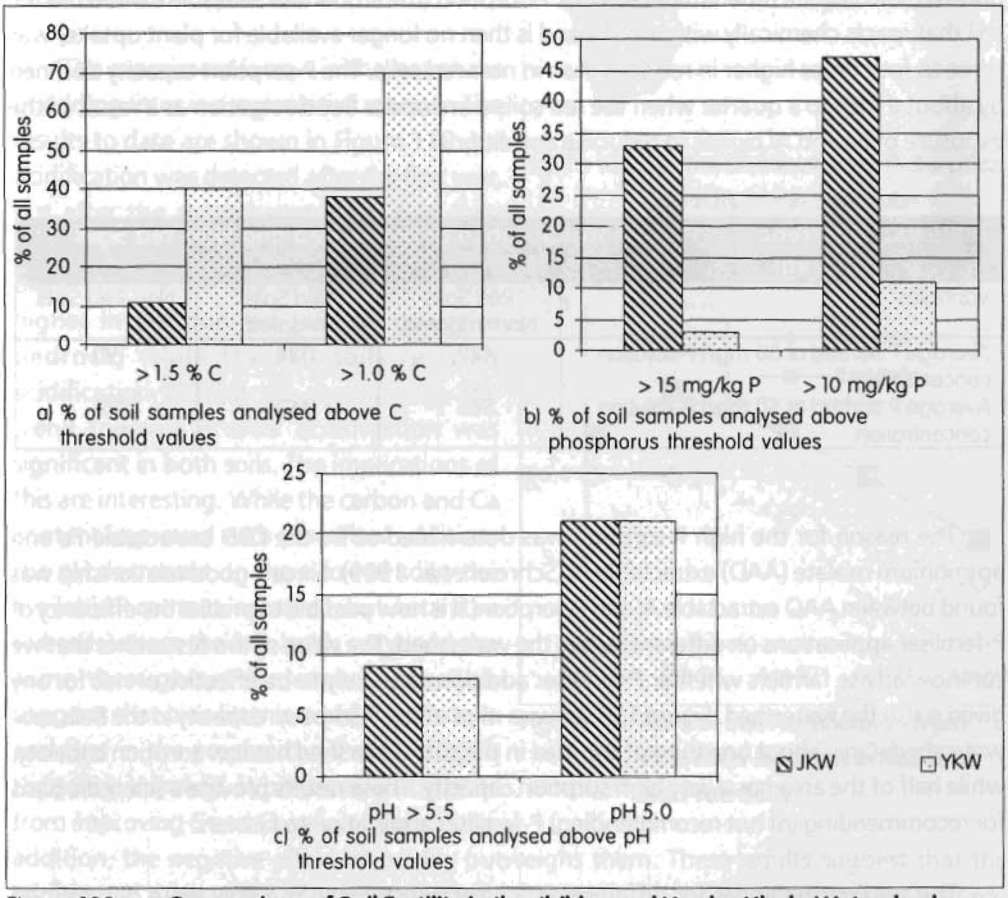


Figure 108a-c: **Comparison of Soil Fertility in the Jhikhu and Yarsha Khola Watersheds Based on Two Different Threshold Values, Adequate and Desirable, for C, Available P, and pH (JKW n = 200, YKW n = 340)**

- significantly higher crop rotations (average 2.7 crop rotations per year in the JKW compared with1.9 crop rotations per year in the YKW).

Only 10 per cent of the samples from the YKW had adequate P levels (Figure 108b), compared with 45 per cent of those from the JKW. One of the reasons for this difference is that phosphate fertilisers are often used in the JKW but only rarely in the YKW.

Soil acidity is of great concern. Only 20 per cent of all samples from both areas had adequate pH values and less than 10 per cent pH values in the desirable range (Figure 108c). There was no difference in the soil acidity between the two sample sets. The low values have serious implications for organic matter decomposition, P availability, Al toxicity and micro-nutrient availability.

### *Results from P Sorption Experiments*

The laboratory experiments showed that the phosphorus sorption capacity of red and non-red soils is quite different (Table 100). P-sorption (the amount of available P added to the soil that reacts chemically with the soil and is then no longer available for plant uptake) was three to four times higher in red soils than in non-red soils. The P-sorption capacity declined by about a fifth to a quarter when the red soils were under flood irrigation as a result of the exposure of Fe and Al oxides to reducing conditions.

Table 100: **Differences in Phosphorus Sorption between Red and Non-red Soils (mg/kg)**

| Variables | Red Soils Non-irrigated | Red Soils Irrigated | Non-Red Soils |
|---|---|---|---|
| Average P sorbed at 30 mg/l P-solution concentration | 422 | 320 | 190 |
| Average P sorbed at 50 mg/l P-solution concentration | 565 | 462 | 261 |

The reason for the high P-sorption was determined to be the CBD extractable Fe and ammonium oxalate (AAO) extractable Al (Schreier *et al.* 1999). Since a good relationship was found between AAO extractable Al and P-sorption, it is now possible to predict the efficiency of P-fertiliser applications on different soils in the watershed. The value of this research is that we can now advise farmers whether P-fertiliser additions are likely to be effective or not for any given soil in the watershed. Figure 109 shows a map of the P-sorption capacity in the Bela sub-watershed. Only about one third of the area in the sub-watershed has low sorption capacity, while half of the area has a very high sorption capacity. These results provide a scientific basis for recommending (or not recommending) P-fertiliser application to farmers.

The nutrient balances for different agricultural systems in the JKW were determined during additional research carried out by Brown (1997), Brown *et al.* (1999), and Brown and

Schreier (this volume). The results confirm that not only is phosphorus deficient in most soils but that there is an annual deficit in inputs. Rainfed maize dominated crop rotations were found to have the greatest P deficits, while the irrigated rice systems were at a much lower risk of long term losses of nutrients. The results indicate that current management practices are mining the soil nutrient pool and if continued may have a long-term negative impact on productivity—unless greater efforts are made to increase manure and fertiliser inputs and to promote mycorrhizal inoculation.

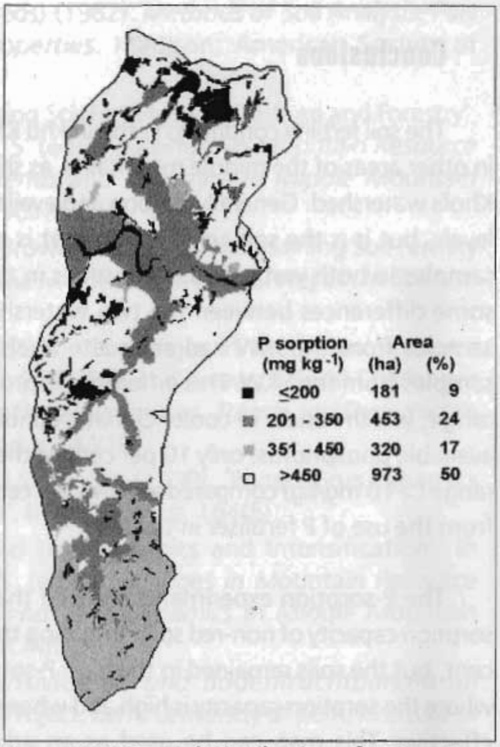


Figure 109: **Spatial Distribution of P-Sorption Capacity in the Bela sub-watershed**

### *Results of the Pine Litter Acidification Experiment*

The experiment is now in the last phase of adding litter in a cumulative manner. The results to date are shown in Figure 110. No acidification was detected after the first year, but after the second year there was clear evidence that soil acidification was taking place. Initially the rate of acidification was higher in the non-red soils on quartzite bedrock, while the red soils resisted acidification. During the second year, the trend towards greater acidification was significant in both soils. The implications of this are interesting. While the carbon and Ca content improved with pine litter addition, the pH decreased. In the non-red soils, the available P content increased, but not in the red soils where the low levels remained the same throughout the experiment. This suggests that pine litter is acidifying the soils and that in the process the P availability in red soils is impaired. While there are benefits from improving C and Ca values by pine litter addition, the negative effect on acidity outweighs them. These results suggest that the addition of other types of litter is needed for there to be a positive impact on nutrient management.

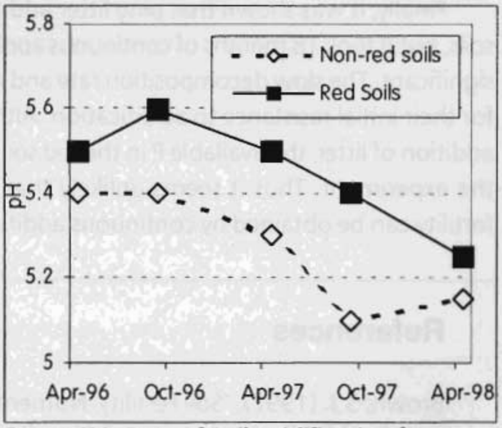


Figure 110: **Rate of Soil Acidification from Pine Litter Addition in Red and Non-red Soils**

## Conclusions

The soil fertility conditions in the Jhikhu Khola watershed are representative of conditions in other areas of the middle mountains, as shown in the comparative study with the Yarsha Khola watershed. Generally, carbon and available phosphorus levels are well below desirable levels, but it is the soil acidification that is of greatest concern. About 80 per cent of all samples in both watersheds had values in the inadequate pH range of <5.0. There were some differences between the two watersheds in terms of soil carbon: one third of the samples from the JKW had adequate levels (>1% C), compared with two thirds of the samples from the YKW. This difference is probably explained by the difference in elevation range, which results in cooler climatic conditions. The reverse situation was observed for available phosphorus: only 10 per cent of the samples from the YKW were in the adequate range (>10 mg/kg) compared with 45 per cent of those from the JKW. This difference results from the use of P fertiliser in the JKW.

The P-sorption experiments showed that red soils had almost twice the phosphorus sorption capacity of non-red soils. Irrigating the red soil reduced the sorption by about 25 per cent, but the soils remained in the high P-sorption category. A map was produced to show where the sorption capacity is high and where the application of P-fertiliser might not be very effective. This map can be used as an advisory tool for farmers in making P-fertiliser application recommendations. More than 50 per cent of the Bela sub-watershed was shown to have soil conditions that are unlikely to respond significantly to P fertiliser applications.

Finally, it was shown that pine litter additions to red and brown soils are acidifying the soils, but it took 18 months of continuous application of litter before the acidification became significant. The slow decomposition rate and Al buffering in the red soils are the likely reason for their initial resistance to acidification. Although the soil carbon can be improved by the addition of litter, the available P in the red soils did not increase significantly over the time of the experiment. Thus it seems unlikely that significant improvements in agricultural soil fertility can be obtained by continuous addition of pine litter.

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