DEPARTMENT FOR INTERNATIONAL DEVELOPMENT

STRATEGY FOR RESEARCH ON RENEWABLE NATURAL RESOURCES

NATURAL RESOURCES SYSTEMS PROGRAMME

FINAL TECHNICAL REPORT

DFID Project Number

R6757

Project title

Soil Fertility Management for Sustainable Hillside Farming Systems in Nepal

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Organisation

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NRSP Production System	*Date*
Hillsides	January 1997-December 1999

CONTENTS

2. EXECUTIVE SUMMARY

The purpose of this project was to determine the factors influencing the maintenance of soil fertility in the mid-hills of Nepal and to develop better means of sustaining fertility. The means of determination was to be via the use of existing knowledge gained in surveys and via field experimentation. The development context for this work was that envisaged by the Nepal Agriculture Perspective Plan which planned for a substantial increase in agricultural production in the mid-hills of Nepal accompanied by increased applications of fertilizer.

The research activities were in collaboration with scientists at ARS-Lumle (LARC) and ARS-Pakhribas (PAC), and farmers in 4 Village Development Committees, and especially 7 villages. Numerous changes in personnel occurred during the project consequent upon the absorption of LARC and PAC into the National Agricultural Research Council.

The research activities included the establishment and maintenance of field experiments, collation of information from the literature and unpublished sources, building simple nutrient budgets for typical households, and a large socio-economic survey of 2081 households. The field experiments were established at 7 sites across Nepal to investigate the effects of manure and fertilizer, alone and together, on crop yields and soil properties. These experiments were researcher-designed on farmers' fields, the cropping systems were as practised in those localities, and the treatments were based on local and recommended practices. The design allowed the residual effects of manure on crop yields and soils to be quantified; such measurements had not been collected previously in Nepal. Previous social, economic and agro-ecological surveys, together with the present survey, demonstrated the important role of manure in the maintenance of fertility but its high demand for labour.

Ouputs from the project were: first, a series of systems-based nutrient balances for the major farming systems in the mid- and high-hills of Nepal were produced in papers and in computer spreadsheets; second, quantitative exposition of the effects of manure and fertilizer on long-term fertility of soils of mid-hills with common crop sequences was completed in the short-term via re-analysis of past experiments and the establishment of field experiments with typical cropping systems; finally the synthesis of local knowledge from surveys and experimental results and their communication to farmers and scientists was, as agreed at the outset of the project, achieved to the extent practicable for a project acknowledged to take longer than 3 years.

The project has contributed to DFID's development goals by identifying the constraints to soil fertility management contributing to the poor food self-sufficiency of the poorer households in the mid-hills of Nepal. The project contributed significantly to the Programme goal of increasing food production in the mid-hills by the involvement of LARC, PAC and Village Development Workers in an evolving programme of work.

3. BACKGROUND

The farming systems in the middle hills of Nepal have been described by Kiff *et al.* (1995)[1] and are characterised by strong links between the 3 major components: livestock, forest and crop production. This interdependence of resource use has been a key to the cycling of nutrients in Nepalese hill agriculture but changes to, or pressures on, those components are reflected in soil fertility. Among the more important changes recently are the reduction in livestock numbers, forest degradation, reduced availability of labour, development of community forests and stall-feeding of cattle (Turton *et al*., 1995[2]). Several surveys have indicated that farmer concern about long-term soil fertility is widespread and, in some regions, well-founded (Sthapit *et al*., 1988[3]; Vaidya *et al*., 1995[4]). Little is known of the past and current status of soil fertility in the middle hills and there are few historical samples that can act as reference points.

Soil fertility involves the combination of chemical, physical and biological components that influence crop growth and impose limitations on yield (Kiff *et al*., 1995[1]). To date, there has been most emphasis on chemical aspects of fertility, although farmers have alluded to the degradation of soil structure and increased draft requirement for tillage following applications of chemical fertilizers (Turton *et al*., 1995[2]). The present major sources of nutrients for crops are from farmyard manure (FYM) and compost with only low inputs of fertilisers (typically <25 kg N ha^{-1}). Combinations of inorganic and organic fertilisers are reported in surveys as cost effective (Kiff *et al*., 1995[1]) but guidance on how to achieve this optimally is not available.

The recently published Nepal Agriculture Perspective Plan (1995)[5] envisages a substantial increase in agricultural (especially horticultural and livestock) production in the mid-hills accompanied by increased applications of fertiliser. This, then, may be added to the changes already facing hillside production systems which, in summary, are resulting in the movement of crop production onto more marginal lands and the breakdown of traditional farming practices. The recently published development plan detailed by FAO/World Bank (1995)[6] identified a key area for research as the development of an appropriate mix of organic and inorganic nutrient sources with emphasis on the gains and losses of nutrients accompanying the application of manures, fertilisers and crop residues.

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[1] Kiff, E., Turton, C., Tuladhar, J.K. and Baker, R. (1995). A review of literature relating to soil fertlity in the hills of Nepal. NRI/LARC project, Chatham.

[2] Turton, C., Vaidya, A., Tuladhar, J.K., and Joshi, K.D. (1995). An analysis of soilfertility systems in the hills of Nepal. A joint project between LAC and NRI. (Draft).

[3] Sthapit, B.R., Gautam, M., Ghale, N., Gurung, J., Gurung, K.J., Paudel, D.R.S. and Subedi, K.D. (1988). The results of SFT Samuhik Bhraman: traditional methods of sustaining crop productivity in the lower hills (300-700m) The problems and potential. LARC Technical Paper 1988/19.

[4] Vaidya, A., Turton, C., Joshi, K.D. and Tuladhar, J.K. (1995). A systems analysis of soil fertility issues in the hills of Nepal: implications for future research. LARC Seminar Paper 95/4.

[5] Nepal Agriculture Perspective Plan (1995). Final report prepared for the National Planning Commission, HMGN and Asian Development Bank.

[6] FAO/World Bank (1995). Nepal: Agricultural Technology and Dissemination Project. Report No 82/95 CP-NEP 49.4.

Gregory (1995)[7] highlighted the need for research to address the pressing issues of soil fertility management in Nepal. He drew attention to the need to quantify current nutrient balances in specified farming systems and to derive management strategies that enhance the effectiveness of inputs as well as reduce losses. In particular, he recommended that, given the importance of organic inputs, future research should involve some long-term (at least 5 years) experiments in which the residual benefits of manures and fertilisers could be assessed; this would lead, in turn, to the development of integrated nutrient management ensuring the optimum use of the limited resources available to hill farmers. This, and other recommendations, has now been adopted as part of the soil fertility research programme at ARS-Lumle (Gregory, 1996[8]).

4. PROJECT PURPOSE

The strategic and development plan for the National Agricultural Research Council (NARC) of Nepal identified soil fertility improvement as a key area for hillside research (FAO/World Bank, 1995[6]) which is commensurate with the objectives stated in the 5-year plan of His Majesties Government of Nepal (National Planning Commission, 1998[9]). In a development context in the mid-hills of Nepal this means enabling farmers to be better able to manage change in traditional systems by improving soil fertility so that sustainable crop production practices could be developed to meet the increased demand for food.

The purpose of this project was therefore to determine those factors influencing the maintenance of soil fertility in the mid-hills of Nepal and to develop better means of sustaining fertility through experimentation and the utilization of existing knowledge gained in surveys. These improved methods would be promoted through field experiments and workshops.

Four principal outputs were originally proposed, namely:

1). A series of systems-based nutrient balances for the major farming systems in the mid-hills of Nepal;

2). Quantitative exposition of the effects of manure and fertiliser on long-term fertility of soils of mid-hills with common crop sequences

3). Local knowledge gained from surveys and experimental results will be synthesised and communicated to farmers and scientists; and

4). (In phase 2) Development of recommendations for farmers on the use of fertilisers and manures (integrated nutrient management).

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[7] Gregory, P.J. (1995). Soil fertility in Nepal. Report on a short term consultancy for NRI. 53pp.

[8] Gregory, P.J. (1996). Soil fertility in Nepal. Report of a second short term consultancy for NRI in March/April 1996. 25pp.

[9] National Planning Commission (1998). The Ninth Plan (1997-2002). His Majesty's Government, Nepal. pp 765.

5. RESEARCH ACTIVITIES

The central core of the project was the establishment of some long-term experiments (intended to run for at least 5 years) in which it was possible to measure some of the key transformations of nutrients and their benefits to crops. The experiments were located in Village Development Projects that were well-defined socially and agro-ecologically by staff from ARS-Lumle and ARS-Pakhribas. By synthesizing the existing local knowledge of both farmers (gained through extensive socio-economic surveys) and scientists (gained from agronomic experiments and trials) it is possible to produce a series of nutrient budgets for key farming systems in the mid-hills of Nepal. The synergy arising from experimental measurement and local knowledge was enhanced further by the development of computer-based models to provide farmers with recommendations for systems of nutrient management which integrate the use of fertilizers and manures. Both modelling and controlled experiments were vital because of the high costs of field experimentation and the limited range of environmental conditions that can be experienced in a short term project such as this.

5.1 SYNTHESIS OF LOCAL KNOWLEDGE

A literature search through diverse reports and copious grey literature in the libraries at ARS-Pakhribas and ARS-Lumle together with data on livestock feed utilization obtained from Dr Peter Thorne, NRI, Chatham, UK have provided the basis for this synthesis. More details of this activity are given in Appendix 2.

5.2 MODELLING

A nutrient balance was constructed at a household scale. It included details of nutrient transfers across the boundary of the farming system and also within the household. The generic structure of the model is shown (Fig. 1). To construct a balance the characteristics of the particular farming system within the mid-hills of Nepal were specified and the necessary input data entered. The balance was calculated based on assumptions that had been programmed in an MS Access database. Further details of this activity are given in Appendix 3.

Through linkage with NRSP High Potential project R6751 we further developed this spreadsheet model in two ways. The first development was to use a larger dataset to derive the assumptions of the model. The second was to provide an interface. The purpose of this interface was to create a user friendly means to specify the characteristics of a system.

5.3 FIELD EXPERIMENTATION

5.3.1 Long-term field sites.

Field experiments were established on farmer's fields at 7 sites: 4 of the sites (Pakuwa, Chambas, Dordor Tar and Dordor Gaun) were managed from Agricultural Research Station, Lumle and the other 3 (Pakhribas, Kholitar, and Sindhuwa) were managed from Agricultural Research Station, Pakhribas. Three sites (Pakuwa, Chambas and Kholitar) are khet land on which rice is grown in rotation with wheat. One site (Dordor Tar) is an example of Tar land where upland rice is grown in rotation with blackgram. The 3

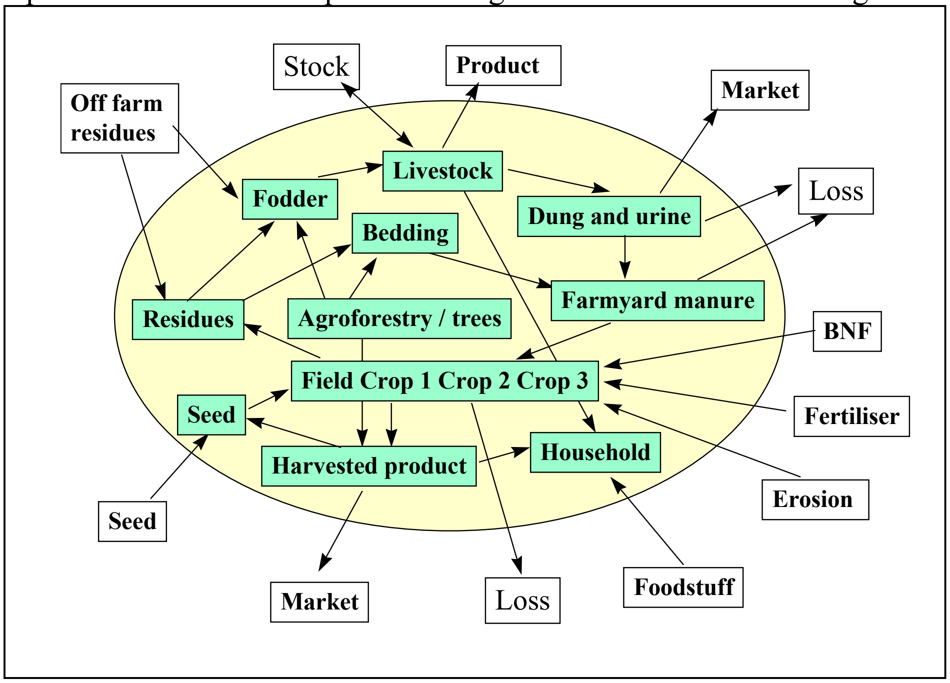


Figure 1. Schematic representation of the pools and flows included in the nutrient balance model

Table 1. Description of location of each of 7 field sites.

Site	District	Village Development Committee	Land Type[1]	Altitude (m above sea level)	Latitude °N	Longitude °E
Dordor Gaun	Tanahun	Bhanu	Bari	1100	28° 10’	84°15’-84°30’
Dordor Tar	Tanahun	Bhanu	Tar	400	28° 10’	84°15’-84°30’
Chambas	Tanahun	Bhanu	Khet	350	28° 10’	84°15’-84°30’
Pakuwa	Parbat	Pakuwa	Khet	1100	28° 15’	83°40’
Pakhribas	Dhankuta	Pakhribas	Bari	1680	27° 17’	87°17’
Kholitar	Dhankuta	Pakhribas	Khet	1430	27°	87°
Sindhuwa	Dhankuta	Murtidhunga	Bari	2150		

[1] Land Type: Khet land is irrigated terrace often lying in valley floors. Bari land is rainfed terrace. Tar land is rainfed ancient river terracing and is locally important.

remaining sites are on bari land and maize is grown either in rotation or in relay with millet (Dordor Gaun and Pakhribas, respectively) or as an intercrop with potato (Sindhuwa).

A detailed description of the location of each site is given in Table 1 .

5.3.2 Experimental Design

The experimental design at each site was a randomized complete block design with 4 blocks (except Sindhuwa which had 3). The nutrient treatments were based on the following principles:

1). Nutrients were applied in accordance with recommended farmer practices which had been developed through extensive field trials in the command areas of ARS-Lumle and ARS-Pakhribas in the mid-hills of Nepal.
2). It was recognized that actual application rates of manure by farmers were not always equivalent to recommended rates, so in this experiment rates of manure application were based on the application rate of inorganic N and P.
3). Manure and inorganic P (as DAP) and K (as muriate of potash) were applied as a basal dressing. Fertilizer N was applied half as a basal dressing (DAP and some urea) and half as a top-dressing (all urea).
4). Locally produced manure was applied at each site. The amount applied was dependent upon the chemical composition measured before incorporation.
5). It was recognized that animal numbers are declining on farms in the mid-hills of Nepal and therefore the availability of manure is decreasing. Consequently, the secondary treatment involved application of half the previously determined rate of manure, since this was more likely to represent future farmer practice.

The 7 nutrient treatments in each block for every crop were as follows:
1). Zero-input
2). Farmer recommended practice (fertilizer, based on recommended inorganic N input)
3). Farmer recommended practice (manure, based on recommended inorganic N input)
4). Farmer recommended practice (0.5 treatment 2 and 0.5 treatment 3)
5). Half farmer recommended practice (fertilizer)
6). Half farmer recommended practice (manure)
7). Half farmer recommended practice (0.5 treatment 5 and 0.5 treatment 6).

Recommended farmer practice is defined for each cropping system in the following table (Table 2).

Plot sizes were generally 6 m x 4 m, except at Kholitar where they were 5 m x 5 m and at Sindhuwa where they were 6 m x 5 m (replicates 1 and 2) and 4 m x 7.5 m (replicates 3) (Table 3). The spacing between plants for different crops at each location is indicated in Table 3.

Table 2. Definition of best farmer practice for each of the cropping systems.

System	Crop	Variety	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
Rice-wheat	Rice	Local	50	15	15
	Wheat	Annapurna-4	80	15	15
Maize/millet	Maize	Manakamana 1	90	30	30
	Millet	Local	-	-	-
Upland Rice/Blackgram	Upland rice	Local	40	15	15
	Blackgram	Local	-	-	-
Potato/Maize	Maize	Madi White			
	Potato	Sakari Seto	90	60	60

Table 3. Plot sizes and row spacings at each location.

Location	Crop	Variety	Plot Size	Row Spacings
Dordor Gaun	Maize	Manakamana-1	6 m x 4 m	75 x 25 cm
	Millet	Okhle		10 x 10 cm
Pakhribas	Maize	Manakamana-1	6 m x 3.75 m	75 x 25 cm
	Millet	Okhale-1		10 x 10 cm
Dordor Tar	Upland Rice	Tauli	6 m x 4 m	20 cm rows
	Blackgram	Mash		40 x 20 cm
Pakuwa	Rice	Akle	6 m x 4 m	20 x 20 cm
	Wheat	Annapurna-4		25 cm rows
Chambas	Rice	Makawanpur-1	6 m x 4 m	20 x 20 cm
	Wheat	Annapurna-4		25 cm rows
Kholitar	Rice	Atte Local	5 m x 5 m	20 x 20 cm
	Wheat	Annapurna-4		20 cm rows
Sindhuwa	Potato	Sarkari Seto	30 m^2	50 x 25 cm
	Maize	Madi White		100 x 25 cm

5.3.3 Sowing and Harvesting Schedule

The dates of sowing or transplanting, top-dressing N fertilizer and harvesting every crop in each year at all locations are shown in Table 4.

5.3.4 Standard measurements at each site

5.3.4.1 Meteorological data

Daily records of maximum and minimum temperature and rainfall were taken at each site beginning in 1997 at all sites except Sindhuwa, which was initiated in 1998. Monthly average values for each location are shown in figures 2 and 3.

5.3.4.2 Basal soil measurements

Before any treatments were applied to the plots, 3-4 soil samples from 4 layers (0-25, 25-50, 50-75 and 75-100 cm where possible) were collected from each plot, and bulked to give a composite sample. These were air dried, sieved to pass a 2 mm sieve, and divided into two. One part was retained in Nepal, while the other part was sent to the UK. At least 8 of the samples (*i.e.* a minimum of 2 per block) were analysed for pH, organic matter, available P, total N, CEC and exchangeable Ca, Mg, K, Na plus micronutrients in Nepal, and for particle size at The University of Reading. The water release curves of soils from a few sites were also produced at Reading.

Eight undisturbed samples were also collected from each layer to measure bulk density.

5.3.4.3 Routine soil measurements

At the end of each cropping cycle a bulked sample of soil was taken from the 0-25 cm layer and analysed for total N, available P, K, organic matter and pH in Nepal.

5.3.4.4 Plant measurements

a). During the experiment.

4 plants or 4 x 50 cm rows were collected at flowering. Plant height and dry weight was determined. Dried plant material was analysed for N, P and K in Nepal.

b). At harvest.

4 plants or 4 x 50 cm rows were sampled. The plants were divided into grain and straw, and fresh and dry weights determined. Dry grain and straw were analysed for N, P and K in Nepal.

5.3.5 Particular measurements at each site

5.3.5.1 Volumetric water content

Theta probe soil moisture sensors (Type ML2; Delta-T Devices, Cambridge, UK) were installed at 6 depths (10, 20, 30, 40, 60 and 90 cm) in the maize-millet trials at Pakhribas and Dordor Gaun in April 1998. At Pakhribas the theta probes were installed in 3 replicates of treatments 1, 2 and 3 (listed above). At Dordor Gaun theta probes were installed in the control and manure plots of 2 replicates only. Millivolt outputs were measured weekly at Pakhribas and fortnightly at Dordor Gaun.

Theta probes installed at Pakhribas were calibrated in the laboratory at ARS-Pakhribas. Water was added to 800-1000 g of samples of soil from each of the six depths to generate a range of soil moisture contents. These samples were packed to a constant depth in a beaker and the millivolt output of the theta probe was then measured. A sample of soil was then dried at 105°C for 48 h to determine the gravimetric soil moisture content. The bulk density of the different soil layers at Pakhribas had been determined previously (Table 5), and allowed the calculation of the volumetric soil moisture content. Figure 4 shows the relationship between mV output and volumetric soil moisture content for soil at Pakhribas.

A similar procedure was followed at The University of Reading for soils from Dordor Gaun, to establish a calibration curve between volumetric soil moisture content and mV output for theta probes installed at that site.

Table 5. Average (n=18) bulk density for different soil layers at Pakhribas. A standard error of the mean is also shown.

Soil Layer	Mean (g cm^{-3})	Standard Error
10	1.426	0.038
20	1.520	0.041
30	1.573	0.032
40	1.536	0.033
60	1.511	0.034
90	1.517	0.037

5.3.5.2 Soil solution sampling using ceramic cups

At Dordor Tar and Gaun and Pakhribas in April 1998, 4 ceramic cups solution samplers (1 bar high flow - B1M3; Soilmoisture Equipment Corp., USA) following the design of Webster *et al*. (1993)[1] were installed in all replicates of treatments 1, 2 and 3 (listed above). The samplers were installed to a depth of 75 cm at Dordor Tar and 90 cm at the other two sites by augering a 6 cm diameter hole, inserting the cup and back-filling with sieved soil. Solution samples were taken following the application of a 50 kPa suction for 24 h, whenever possible, at 14 d intervals at Dordor Gaun and Dordor Tar, and at 7 d intervals at Pakhribas beginning in July 1998 and continuing until November 1998. Sampling began again in May/June 1999 and continued at the same frequency as in 1998 until October 1999. Daily measurements were taken for a period of 10 days post top-dressing at all 3 sites in 1999. All solutions were stored at 4°C prior to shipment to the UK for analysis. Samples were always analysed for nitrate and ammonium. Some samples were analysed for P and K.

5.3.5.3 Application of ^{15}N-labelled fertilizer

Maize in rotation (Dordor Gaun) and in relay with millet (Pakhribas), and upland rice (Dordor Tar) were top-dressed with N in June 1998. ^{15}N-labelled urea (10.3616 atom%) at the appropriate fertilizer application rate was applied in solution (1 l m^{-2}) to 6 m^2 microplots within each of the 16 fertilized plots (i.e. 4 treatments) at each site.

[1] Webster, C.P., Shepherd, M.A., Goulding, K.W.T. and Lord, E. (1993). Comparisons of methods for measuring the leaching of mineral nitrogen from arable land. Journal of Soil Science 44: 49-62.

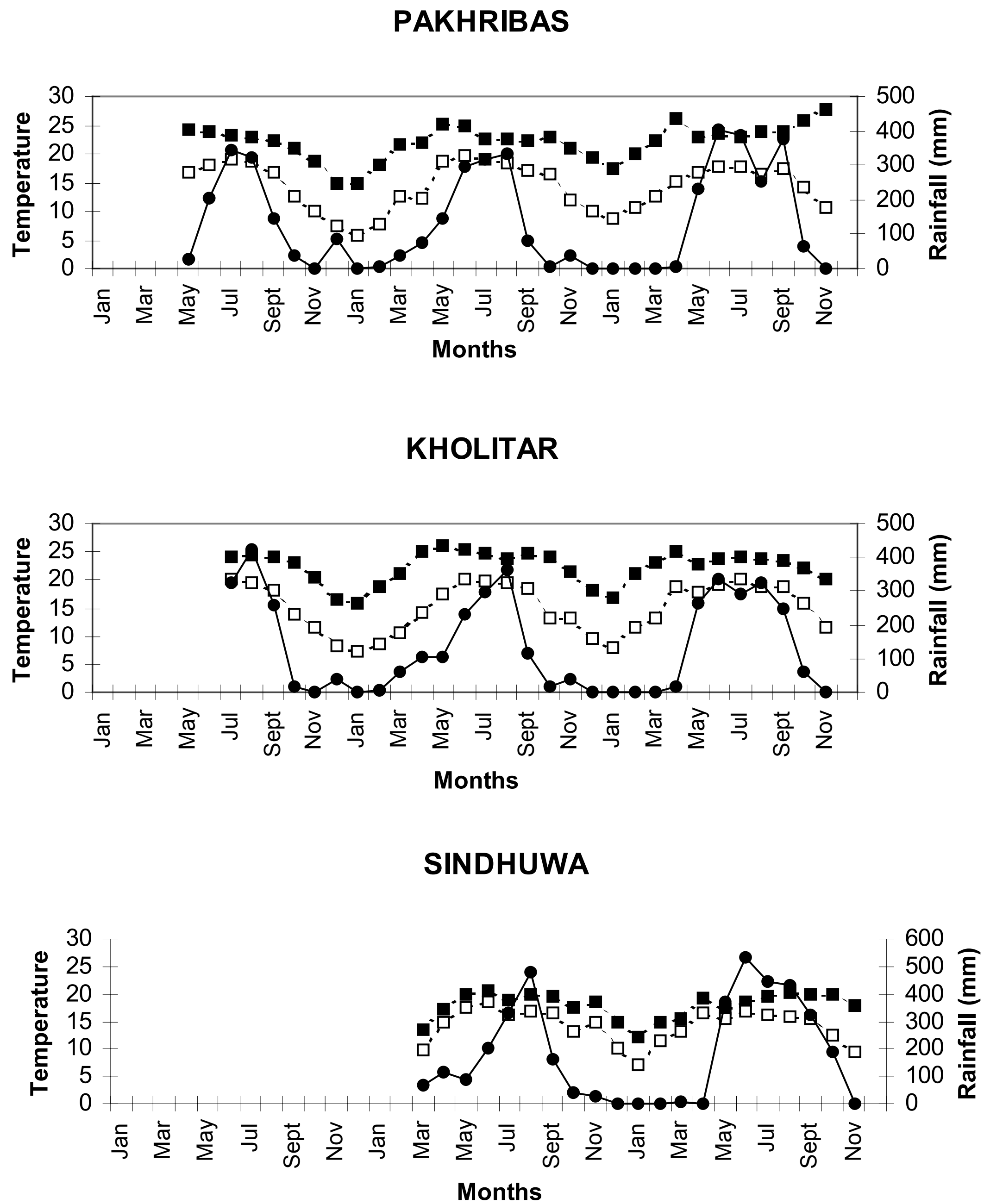
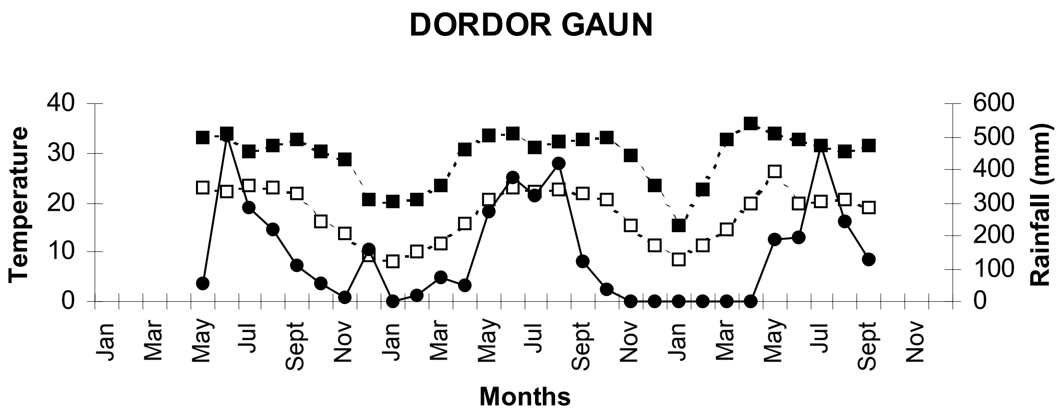
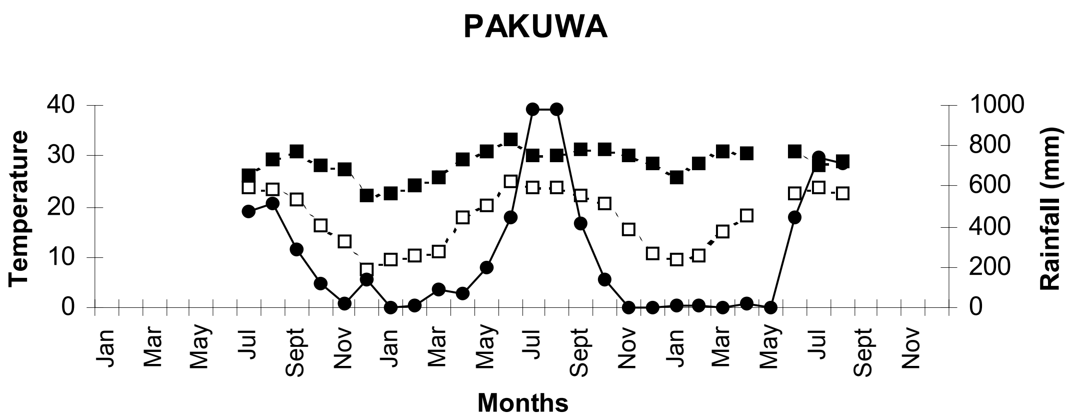


Figure 2. Meteorological data for 3 field sites at ARS-Pakhribas. Solid squares represent monthly average maximum temperature, open squares represent monthly average minimum temperature and solid circles represent monthly rainfall totals. Axis begins January 1997 and ends December 1999.





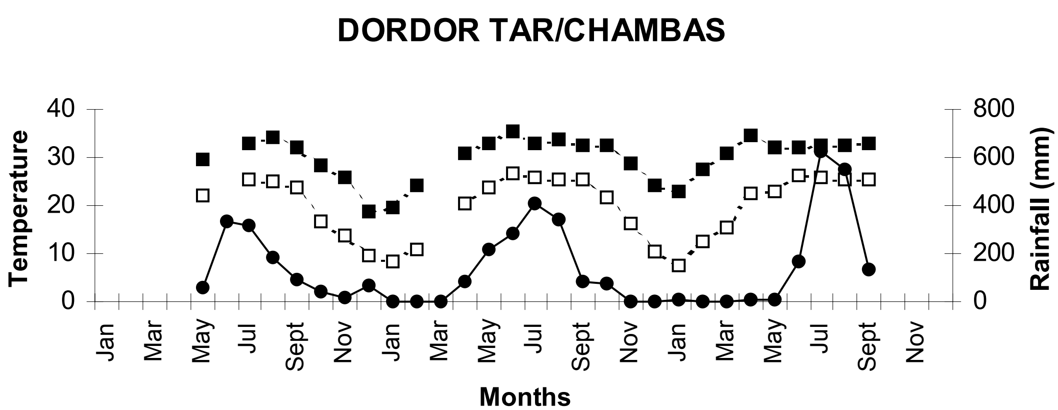
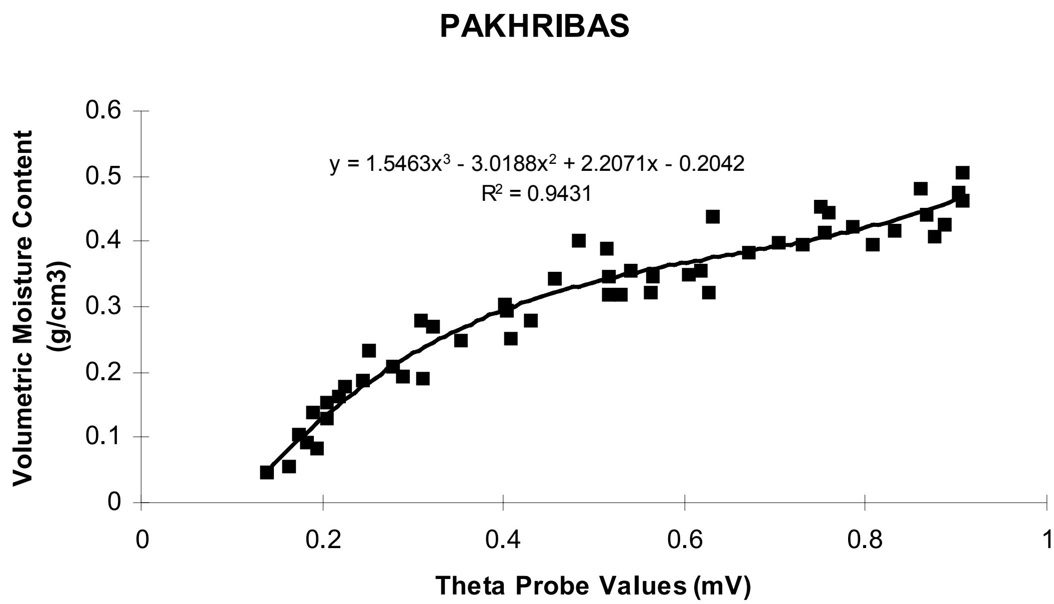


Figure 3. Meteorological data for 4 field sites at ARS-Lumle. Solid squares represent monthly average maximum temperature, open squares represent monthly average

minimum temperature and solid circles represent monthly rainfall totals. Axis begins January 1997 and ends December 1999.



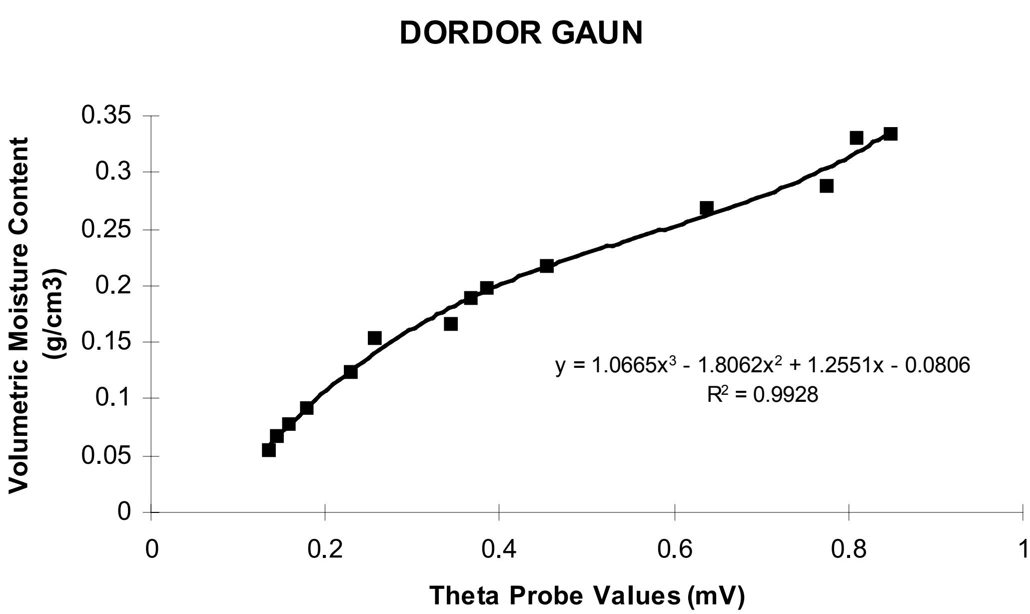


Figure 4. Calibration curves for volumetric moisture content on millivolt output for Theta Probes at Pakhribas and Dordor Gaun in the mid-hills of Nepal. Equations are given on the figures.

5.3.5.4 Sampling of ^{15}N-labelled microplots

At harvest, maize or upland rice plants from an area of 0.5 m x 0.7 m in one quarter of the microplot were sampled at ground level. These were divided into grain and straw and oven dried at 80°C for 48 h. They were shipped to The University of Reading where they were ground to pass a 2 mm sieve. The N content and ^{15}N enrichment of these plant samples was determined by total combustion on a Roboprep C and N analyser (Europa Scientific, Crewe) linked to a VG 602 mass spectrometer. Millet and blackgram plants were sampled from an area of 0.5m x 0.7m in another quarter of the microplot at the next harvest.

In the area from where the plants had been sampled a soil sample was taken. Soil was dug to a depth of 20 cm from within a 30 cm x 30 cm grid placed on the soil surface. The soil was sieved through a 10mm mesh, mixed thoroughly and sub-sampled. Two further soil samples were also taken from the 20-40 and 40-60 cm soil layer in the base of the hole using a 4 cm diameter auger at Dordor Gaun and Dordor Tar and a 6 cm auger at Pakhribas. These soils were air dried, ground and analysed for total N and the ^{15}N enrichment of the N on a Roboprep C and N analyser.

5.3.6 Field experiments to measure biological nitrogen fixation by blackgram

1). 1 m^2 microplots were located in the middle of 2 m x 2 m plots of blackgram, mustard and niger in 1997. Immediately after sowing ^{15}N-labelled ammonium sulphate was applied at a rate of 10 kg N ha^{-1} as a solution uniformly to each of the 9 plots. Plants were sampled at harvest in December 1997, and a sample of soil from 0-20 cm layer was also taken. These samples were analysed for N content and ^{15}N enrichment as outlined above.

2). In a similar manner to that adopted by McNeill *et al*. (1998)[2] the residual ^{15}N fertilizer applied to upland rice in 1998 provided a more uniform labeling of the soil N pool for the measurement of biological nitrogen fixation by blackgram in 1998. 1 m^2 plots of niger, the more suitable reference crop identified in 1997, were sown within the ^{15}N-labelled microplots. The ^{15}N enrichments of these plants was then compared, according to equations outlined in McNeill *et al.* (1998)[11].

5.3.7 Measurement of the fate of urea fertilizer immediately after application

Cores (50 mm i.d.) were inserted to 10 cm depth at ARS-Lumle and at ARS-Pakhribas in July/August 1997, and to 25 cm depth at Pakhribas (maize/millet trial) in June 1998.

^{15}N-labelled urea fertilizer was applied as solution to each core at a rate of 20 kg N ha^{-1} in 1997 and 45 kg N ha^{-1} in 1998 (equivalent to the top-dressing rate). 4 cores were sampled immediately after application, and four more at 1, 2, 4 and either 7 (ARS-Pakhribas) or 10 (ARS-Lumle) days after application. From each core soil samples were taken from the 0-5 and 5-10 cm layer in 1997, and the 0-5, 5-15 and 15-25 cm layers in 1998. The nitrate, ammonium and total N content of the soil from each layer of every core, together with their respective enrichments were determined. Urea was determined

[2] McNeill, A.M., Pilbeam, C.J., Harris, H.C and Swift, R.S. (1998). Use of residual fertilizer ^{15}N in soil for isotope dilution estimates of N_2 fixation by grain legumes. Aust. J. Agric. Res. 49: 821-828

colourimetrically following a modified diacetyl monoxime method (Mulvaney and Bremner, 1979)[3].

A similar experiment was conducted at Pakuwa in August 1998, to measure the recovery of top-dressed N fertilizer applied to drained rice paddies, and to measure the effect on recovery of ^{15}N fertilizer of subsequent reflooding. Cores were inserted to a depth of 15 cm. ^{15}N-labelled urea fertilizer (10.3616 atom%) was applied as a solution to each core at a rate of 25 kg N ha^{-1}. 4 cores were sampled immediately after application and divided into 3 layers (0-5, 5-10 and 10-15 cm). A further set of 4 cores were sampled on the following day. Half of the remaining 16 cores were then flooded, while the rest remained unflooded. Half of the flooded cores and half of the unflooded cores were sampled on day 2 after addition of N. All of the remaining cores were sampled on day 3 after ^{15}N-fertilizer application. Each core was divided into 3 layers and a subsample of soil extracted in 1 M KCl. The nitrate, ammonium and total N content of the soil from each layer of every core, together with their respective enrichments were determined.

5.3.8 Measurement of Nutrient losses in Irrigated Paddies

5.3.8.1 Weir Calibration

The depth and volume of water flowing across a U-shaped weir of known dimensions (207 mm breadth x 306 mm length) in a given time was determined at Pakuwa in August 1998. This enabled a calibration curve between the depth of water flowing across a weir and volume of water discharged to be determined (Fig. 5).

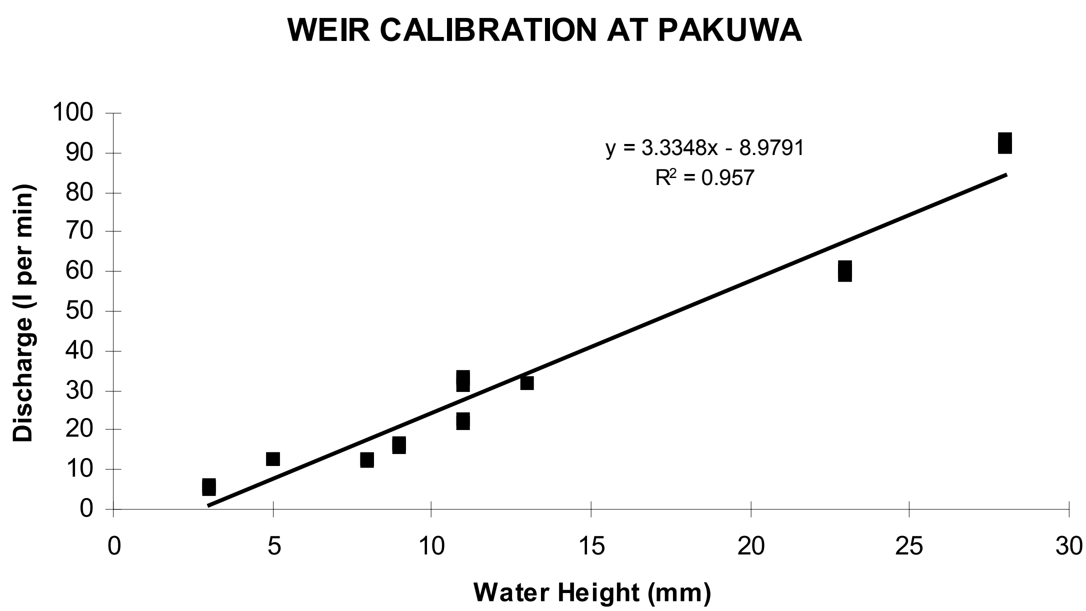


Figure 5. A stage discharge relationship over a constant channel at Pakuwa, August 1998. A calibration equation is given on the figure.

[3] Mulvaney, R.L. and Bremner, J.M. (1979) A modified diacetyl monoxime method for colorimetric determination of urea in soil extracts. Comm. Soil Sci. Plant Anal. 10: 1163-1170

5.3.8.2 Sample Collection and Analysis
Samples of irrigation water were taken every 3 h over two days in late August at Pakuwa. These were analysed for nitrate and ammonium concentration at the University of Reading using a flow injection analyser. Phosphate was measured colorimetrically using an Olsen-P method. Potassium was determined by atomic absorption.

5.3.9 Measurement of gaseous N loss from irrigated paddies
Field measurements of gaseous N losses were made at Pakuwa in early August 1999, approximately 3 weeks after transplantation of rice. Measurements were made in the zero-input treatment, and in the treatments receiving high rates of N application either as fertilizer or manure.

30 cm long PVC tubes (internal diameter 9.5 cm) were inserted into the soil in 3 replicates of each of the 3 treatments to a depth of 20 cm (*i.e.* leaving 10 cm above the soil surface). Gas lids were sealed onto these chambers using silicone sealant and tape in order to measure gas fluxes.

^{15}N-labelled urea (10.3616 atom%) was applied as a solution on 3 August 1999 (day 2) at a rate of 25 kg N ha^{-1} to the fertilized treatments only.

5.3.9.1 Ammonia flux
During the period of sampling air was drawn from around the plants through PTFE tubing at a rate of 5 l min^{-1} by Charles Austen vacuum pumps. The volume of air pumped from each chamber was measured using Remus standard gas meters and controlled by rotameters (Airflow). Ammonia in the gas sample was collected in a Dreschel-headed acid trap between the chamber and the airflow control mechanism. Each acid trap contained 30 ml of 0.02 M orthophosphoric acid. The concentration of ammonia was determined colorimetrically using a modified Indophenol Blue method.

5.3.9.1 Nitrous Oxide flux
Gas samples were taken at intervals from each cylinder in each replicate of each treatment using a gas syringe and transferred to evacuated containers (vacutainers). These samples were analysed in the UK using an Ai 93 Gas Chromatograph with Cygnus software.

5.4 LABORATORY EXPERIMENTS

5.4.1 Gross rates of N mineralization in response to temperature and moisture content
Using a ^{15}N-isotope dilution technique (Barraclough, 1995)[4] to measure gross rates of N mineralization changes were determined in the rate of mineralization of 2 soils (Pakhribas and Dordor Guan) in response to temperature (5, 10, 20 and 30°C) and moisture content (addition of 15 or 17.5 ml water to 40 g soil).

The experiment was repeated for both soils at 2 temperatures (10 and 20°C) and a single moisture content to determine the recovery of ^{15}N-label in the biomass and organic N pools as well as in the ammonium and nitrate pools.

[4] Barraclough, D. (1995) ^{15}N isotope dilution techniques to study soil nitrogen transformations and plant uptake. Fertilizer Research 42:185-192.

Nitrate and ammonium concentrations in soil solution samples from ceramic cups or from 1M KCl extracts of soil were determined colorimetrically on a flow injection analyser (Tecator FIAStar 5010).

5.3.4.2 Basal soil measurements

Before any treatments were applied to the plots, 3-4 soil samples from 4 layers (0-25, 25-50, 50-75 and 75-100 cm where possible) were collected from each plot, and bulked to give a composite sample. These were air dried, sieved to pass a 2 mm sieve, and divided into two. One part was retained in Nepal, while the other part was sent to the UK. At least 8 of the samples (*i.e.* a minimum of 2 per block) were analysed for pH, organic matter, available P, total N, CEC and exchangeable Ca, Mg, K, Na plus micronutrients in Nepal, and for particle size at The University of Reading. The water release curves of soils from a few sites were also produced at Reading.

Eight undisturbed samples were also collected from each layer to measure bulk density.

5.3.4.3 Routine soil measurements

At the end of each cropping cycle a bulked sample of soil was taken from the 0-25 cm layer and analysed for total N, available P, K, organic matter and pH in Nepal.

5.3.4.4 Plant measurements

a). During the experiment.

4 plants or 4 x 50 cm rows were collected at flowering. Plant height and dry weight was determined. Dried plant material was analysed for N, P and K in Nepal.

b). At harvest.

4 plants or 4 x 50 cm rows were sampled. The plants were divided into grain and straw, and fresh and dry weights determined. Dry grain and straw were analysed for N, P and K in Nepal.

5.3.5 Particular measurements at each site

5.3.5.1 Volumetric water content

Theta probe soil moisture sensors (Type ML2; Delta-T Devices, Cambridge, UK) were installed at 6 depths (10, 20, 30, 40, 60 and 90 cm) in the maize-millet trials at Pakhribas and Dordor Gaun in April 1998. At Pakhribas the theta probes were installed in 3 replicates of treatments 1, 2 and 3 (listed above). At Dordor Gaun theta probes were installed in the control and manure plots of 2 replicates only. Millivolt outputs were measured weekly at Pakhribas and fortnightly at Dordor Gaun.

Theta probes installed at Pakhribas were calibrated in the laboratory at ARS-Pakhribas. Water was added to 800-1000 g of samples of soil from each of the six depths to generate a range of soil moisture contents. These samples were packed to a constant depth in a beaker and the millivolt output of the theta probe was then measured. A sample of soil was then dried at 105°C for 48 h to determine the gravimetric soil moisture content. The bulk density of the different soil layers at Pakhribas had been determined previously (Table 5), and allowed the calculation of the volumetric soil moisture content. Figure 4 shows the relationship between mV output and volumetric soil moisture content for soil at Pakhribas.

A similar procedure was followed at The University of Reading for soils from Dordor Gaun, to establish a calibration curve between volumetric soil moisture content and mV output for theta probes installed at that site.

Table 5. Average (n=18) bulk density for different soil layers at Pakhribas. A standard error of the mean is also shown.

Soil Layer	Mean (g cm^{-3})	Standard Error
10	1.426	0.038
20	1.520	0.041
30	1.573	0.032
40	1.536	0.033
60	1.511	0.034
90	1.517	0.037

5.3.5.2 Soil solution sampling using ceramic cups

At Dordor Tar and Gaun and Pakhribas in April 1998, 4 ceramic cups solution samplers (1 bar high flow - B1M3; Soilmoisture Equipment Corp., USA) following the design of Webster *et al*. (1993)[1] were installed in all replicates of treatments 1, 2 and 3 (listed above). The samplers were installed to a depth of 75 cm at Dordor Tar and 90 cm at the other two sites by augering a 6 cm diameter hole, inserting the cup and back-filling with sieved soil. Solution samples were taken following the application of a 50 kPa suction for 24 h, whenever possible, at 14 d intervals at Dordor Gaun and Dordor Tar, and at 7 d intervals at Pakhribas beginning in July 1998 and continuing until November 1998. Sampling began again in May/June 1999 and continued at the same frequency as in 1998 until October 1999. Daily measurements were taken for a period of 10 days post top-dressing at all 3 sites in 1999. All solutions were stored at 4°C prior to shipment to the UK for analysis. Samples were always analysed for nitrate and ammonium. Some samples were analysed for P and K.

5.3.5.3 Application of ^{15}N-labelled fertilizer

Maize in rotation (Dordor Gaun) and in relay with millet (Pakhribas), and upland rice (Dordor Tar) were top-dressed with N in June 1998. ^{15}N-labelled urea (10.3616 atom%) at the appropriate fertilizer application rate was applied in solution (1 l m^{-2}) to 6 m^2 microplots within each of the 16 fertilized plots (i.e. 4 treatments) at each site.

[1] Webster, C.P., Shepherd, M.A., Goulding, K.W.T. and Lord, E. (1993). Comparisons of methods for measuring the leaching of mineral nitrogen from arable land. Journal of Soil Science 44: 49-62.

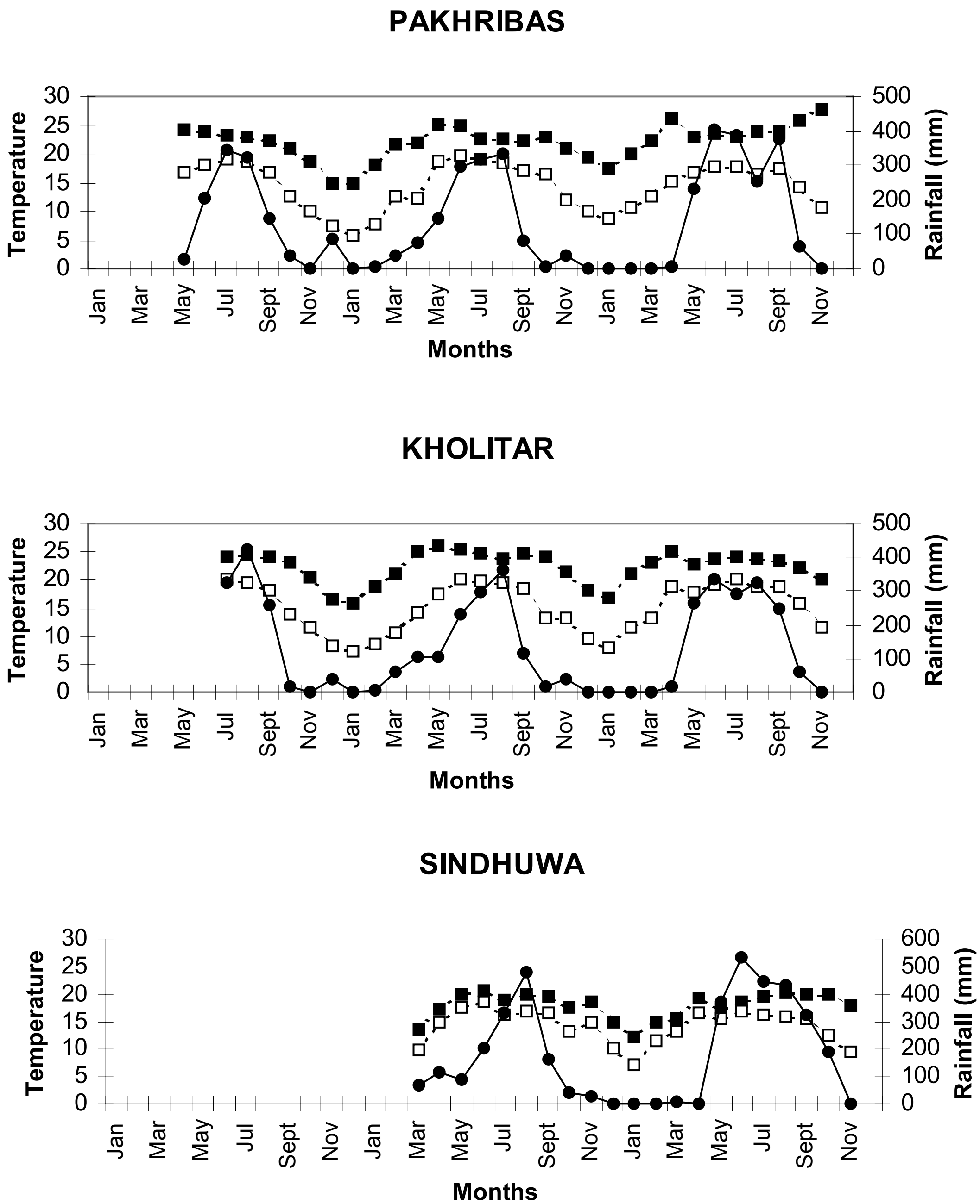


Figure 2. Meteorological data for 3 field sites at ARS-Pakhribas. Solid squares represent monthly average maximum temperature, open squares represent monthly average minimum temperature and solid circles represent monthly rainfall totals. Axis begins January 1997 and ends December 1999.

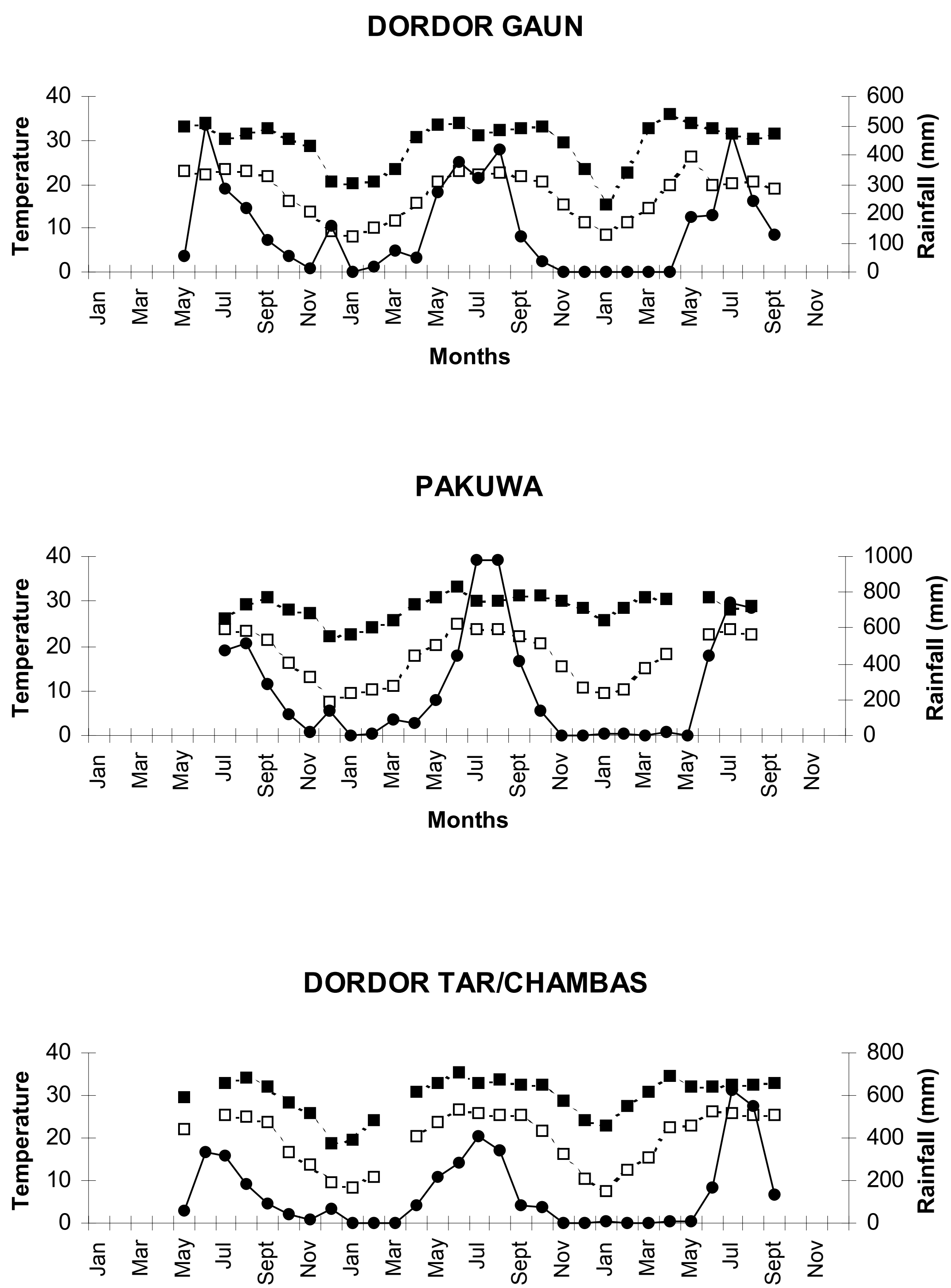
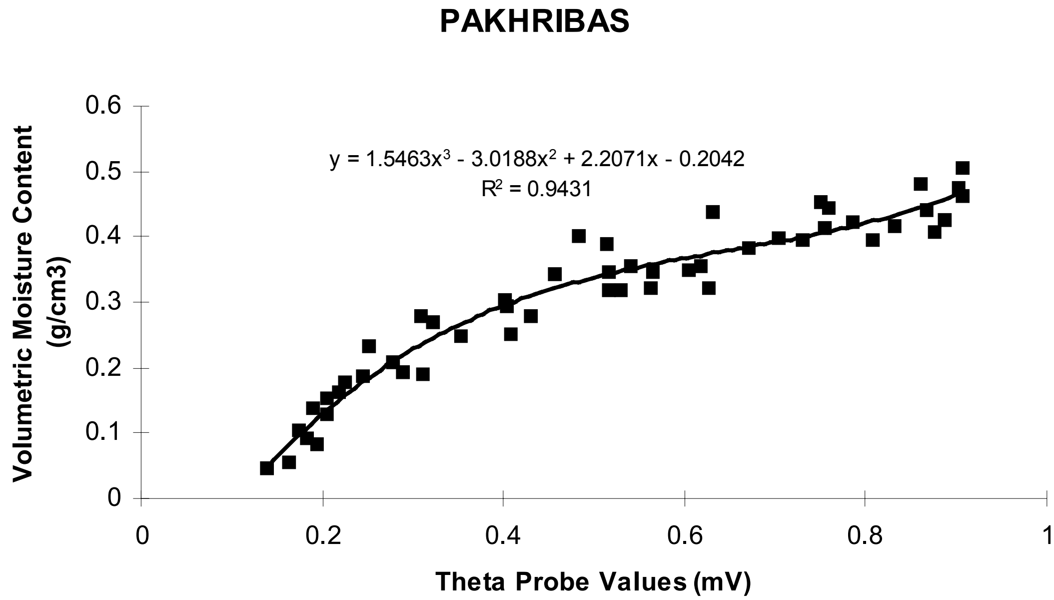


Figure 3. Meteorological data for 4 field sites at ARS-Lumle. Solid squares represent monthly average maximum temperature, open squares represent monthly average

minimum temperature and solid circles represent monthly rainfall totals. Axis begins January 1997 and ends December 1999.



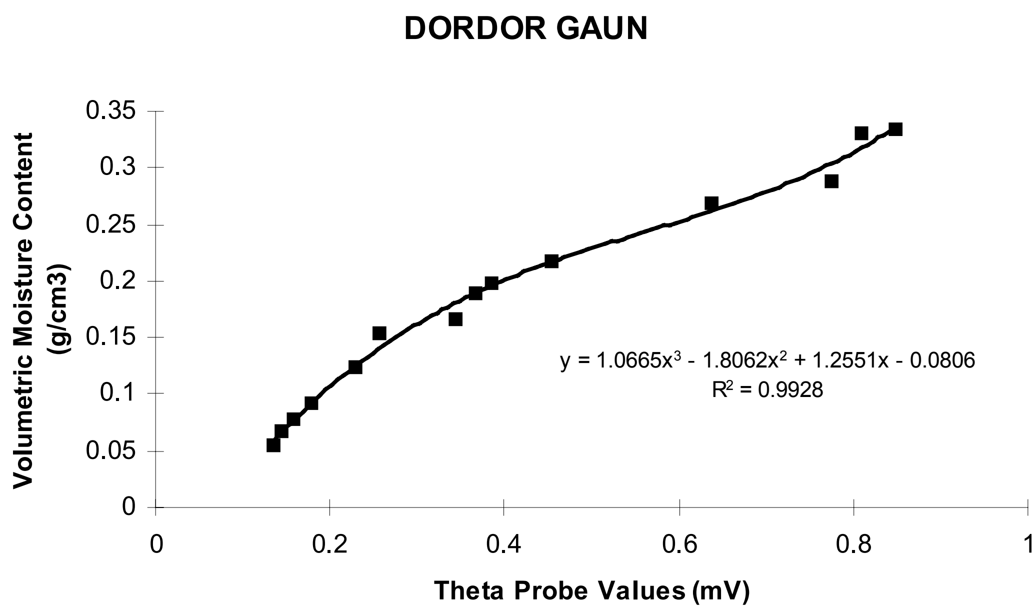


Figure 4. Calibration curves for volumetric moisture content on millivolt output for Theta Probes at Pakhribas and Dordor Gaun in the mid-hills of Nepal. Equations are given on the figures.

5.3.5.4 Sampling of ^{15}N-labelled microplots

At harvest, maize or upland rice plants from an area of 0.5 m x 0.7 m in one quarter of the microplot were sampled at ground level. These were divided into grain and straw and oven dried at 80°C for 48 h. They were shipped to The University of Reading where they were ground to pass a 2 mm sieve. The N content and ^{15}N enrichment of these plant samples was determined by total combustion on a Roboprep C and N analyser (Europa Scientific, Crewe) linked to a VG 602 mass spectrometer. Millet and blackgram plants were sampled from an area of 0.5m x 0.7m in another quarter of the microplot at the next harvest.

In the area from where the plants had been sampled a soil sample was taken. Soil was dug to a depth of 20 cm from within a 30 cm x 30 cm grid placed on the soil surface. The soil was sieved through a 10mm mesh, mixed thoroughly and sub-sampled. Two further soil samples were also taken from the 20-40 and 40-60 cm soil layer in the base of the hole using a 4 cm diameter auger at Dordor Gaun and Dordor Tar and a 6 cm auger at Pakhribas. These soils were air dried, ground and analysed for total N and the ^{15}N enrichment of the N on a Roboprep C and N analyser.

5.3.6 Field experiments to measure biological nitrogen fixation by blackgram

1). 1 m^2 microplots were located in the middle of 2 m x 2 m plots of blackgram, mustard and niger in 1997. Immediately after sowing ^{15}N-labelled ammonium sulphate was applied at a rate of 10 kg N ha^{-1} as a solution uniformly to each of the 9 plots. Plants were sampled at harvest in December 1997, and a sample of soil from 0-20 cm layer was also taken. These samples were analysed for N content and ^{15}N enrichment as outlined above.

2). In a similar manner to that adopted by McNeill *et al*. (1998)[2] the residual ^{15}N fertilizer applied to upland rice in 1998 provided a more uniform labeling of the soil N pool for the measurement of biological nitrogen fixation by blackgram in 1998. 1 m^2 plots of niger, the more suitable reference crop identified in 1997, were sown within the ^{15}N-labelled microplots. The ^{15}N enrichments of these plants was then compared, according to equations outlined in McNeill *et al.* (1998)[11].

5.3.7 Measurement of the fate of urea fertilizer immediately after application

Cores (50 mm i.d.) were inserted to 10 cm depth at ARS-Lumle and at ARS-Pakhribas in July/August 1997, and to 25 cm depth at Pakhribas (maize/millet trial) in June 1998.

^{15}N-labelled urea fertilizer was applied as solution to each core at a rate of 20 kg N ha^{-1} in 1997 and 45 kg N ha^{-1} in 1998 (equivalent to the top-dressing rate). 4 cores were sampled immediately after application, and four more at 1, 2, 4 and either 7 (ARS-Pakhribas) or 10 (ARS-Lumle) days after application. From each core soil samples were taken from the 0-5 and 5-10 cm layer in 1997, and the 0-5, 5-15 and 15-25 cm layers in 1998. The nitrate, ammonium and total N content of the soil from each layer of every core, together with their respective enrichments were determined. Urea was determined

[2] McNeill, A.M., Pilbeam, C.J., Harris, H.C and Swift, R.S. (1998). Use of residual fertilizer ^{15}N in soil for isotope dilution estimates of N_2 fixation by grain legumes. Aust. J. Agric. Res. 49: 821-828

colourimetrically following a modified diacetyl monoxime method (Mulvaney and Bremner, 1979)[3].

A similar experiment was conducted at Pakuwa in August 1998, to measure the recovery of top-dressed N fertilizer applied to drained rice paddies, and to measure the effect on recovery of ^{15}N fertilizer of subsequent reflooding. Cores were inserted to a depth of 15 cm. ^{15}N-labelled urea fertilizer (10.3616 atom%) was applied as a solution to each core at a rate of 25 kg N ha^{-1}. 4 cores were sampled immediately after application and divided into 3 layers (0-5, 5-10 and 10-15 cm). A further set of 4 cores were sampled on the following day. Half of the remaining 16 cores were then flooded, while the rest remained unflooded. Half of the flooded cores and half of the unflooded cores were sampled on day 2 after addition of N. All of the remaining cores were sampled on day 3 after ^{15}N-fertilizer application. Each core was divided into 3 layers and a subsample of soil extracted in 1 M KCl. The nitrate, ammonium and total N content of the soil from each layer of every core, together with their respective enrichments were determined.

5.3.8 Measurement of Nutrient losses in Irrigated Paddies

5.3.8.1 Weir Calibration

The depth and volume of water flowing across a U-shaped weir of known dimensions (207 mm breadth x 306 mm length) in a given time was determined at Pakuwa in August 1998. This enabled a calibration curve between the depth of water flowing across a weir and volume of water discharged to be determined (Fig. 5).

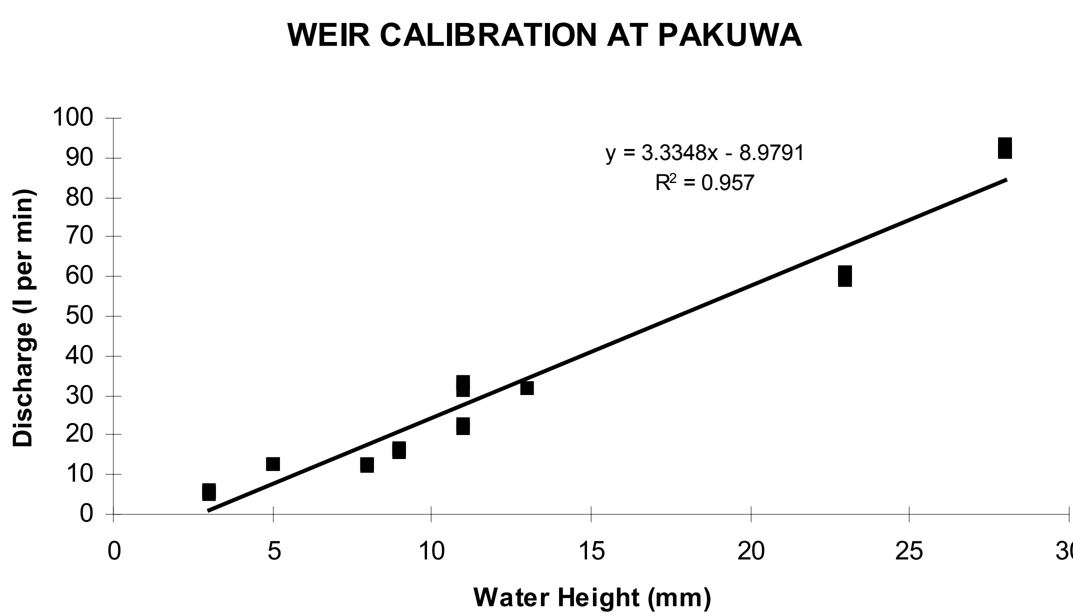


Figure 5. A stage discharge relationship over a constant channel at Pakuwa, August 1998. A calibration equation is given on the figure.

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[3] Mulvaney, R.L. and Bremner, J.M. (1979) A modified diacetyl monoxime method for colorimetric determination of urea in soil extracts. Comm. Soil Sci. Plant Anal. 10: 1163-1170

5.3.8.2 Sample Collection and Analysis

Samples of irrigation water were taken every 3 h over two days in late August at Pakuwa. These were analysed for nitrate and ammonium concentration at the University of Reading using a flow injection analyser. Phosphate was measured colorimetrically using an Olsen-P method. Potassium was determined by atomic absorption.

5.3.9 Measurement of gaseous N loss from irrigated paddies

Field measurements of gaseous N losses were made at Pakuwa in early August 1999, approximately 3 weeks after transplantation of rice. Measurements were made in the zero-input treatment, and in the treatments receiving high rates of N application either as fertilizer or manure.

30 cm long PVC tubes (internal diameter 9.5 cm) were inserted into the soil in 3 replicates of each of the 3 treatments to a depth of 20 cm (*i.e.* leaving 10 cm above the soil surface). Gas lids were sealed onto these chambers using silicone sealant and tape in order to measure gas fluxes.

^{15}N-labelled urea (10.3616 atom%) was applied as a solution on 3 August 1999 (day 2) at a rate of 25 kg N ha^{-1} to the fertilized treatments only.

5.3.9.1 Ammonia flux

During the period of sampling air was drawn from around the plants through PTFE tubing at a rate of 5 l min^{-1} by Charles Austen vacuum pumps. The volume of air pumped from each chamber was measured using Remus standard gas meters and controlled by rotameters (Airflow). Ammonia in the gas sample was collected in a Dreschel-headed acid trap between the chamber and the airflow control mechanism. Each acid trap contained 30 ml of 0.02 M orthophosphoric acid. The concentration of ammonia was determined colorimetrically using a modified Indophenol Blue method.

5.3.9.1 Nitrous Oxide flux

Gas samples were taken at intervals from each cylinder in each replicate of each treatment using a gas syringe and transferred to evacuated containers (vacutainers). These samples were analysed in the UK using an Ai 93 Gas Chromatograph with Cygnus software.

5.4 LABORATORY EXPERIMENTS

5.4.1 Gross rates of N mineralization in response to temperature and moisture content

Using a ^{15}N-isotope dilution technique (Barraclough, 1995)[4] to measure gross rates of N mineralization changes were determined in the rate of mineralization of 2 soils (Pakhribas and Dordor Guan) in response to temperature (5, 10, 20 and 30°C) and moisture content (addition of 15 or 17.5 ml water to 40 g soil).

The experiment was repeated for both soils at 2 temperatures (10 and 20°C) and a single moisture content to determine the recovery of ^{15}N-label in the biomass and organic N pools as well as in the ammonium and nitrate pools.

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[4] Barraclough, D. (1995) ^{15}N isotope dilution techniques to study soil nitrogen transformations and plant uptake. Fertilizer Research 42:185-192.

Nitrate and ammonium concentrations in soil solution samples from ceramic cups or from 1M KCl extracts of soil were determined colorimetrically on a flow injection analyser (Tecator FIAStar 5010).

Total N content was determined by combustion on a Roboprep C and N analyser. Organic N was determined by difference between the total N content and the mineral N content of a sample.

Biomass N was determined by a modified fumigation-extraction technique following extraction of the inorganic N in 1 M KCl. Soil samples were fumigated with chloroform and extracted in 0.5 M K_2SO_4. These extracts were then subject to a concentrated H_2SO_4 digestion using $CuSO_4$ as a catalyst at 360°C for 3 h. The digested extracts were then alkaline steam distilled and the released ammonia trapped in acid prior to titration against sodium hydroxide. ^{15}N enrichment of these biomass extracts was determined after drying the solutions down on a VG622 mass spectrometer.

^{15}N enrichments of the mineral N pools were determined using a modified version of the method of Brookes *et al*. (1989)[1], whereby ammonia evolved from solution after the addition of magnesium oxide (for ammonium), and subsequently Devarda's Alloy (for nitrate) was trapped over 5 days on a disc of Whatman GF/D filter paper acidified with 2.5 M $KHSO_4$. Discs were dried and combusted in a Roboprep C and N analyser linked to a VG622 mass spectrometer to enable the determination of the ^{15}N enrichment of the N_2 gas.

^{15}N enrichments of the total N pool was determined by combustion of ground soil samples on a Roboprep C and N analyser linked to a VG622 mass spectrometer.

5.5 MODELLING SOIL ORGANIC MATTER AND NITROGEN TRANSFORMATIONS WITH SUNDIAL

SUNDIAL has a modular structure in which each module represents one of the major processes of nitrogen turnover in soil. SUNDIAL requires simple field specific information as input data outlined in Table 6. These details were provided only for maize grown at the Pakhribas experimental site (see above).

It also requires weekly rainfall, and mean temperature which were provided from the experimental data at Pakhribas and evapotranspiration data, which were estimated from averaged long-term data from Kathmandu (Mueller, 1982). The model runs on a weekly time-step.

A user-defined soil type was used based on the soil characteristics given in table 11. Stocks of soil organic carbon (SOC) were calculated from the measured soil organic matter (SOM) and bulk density according to the following equation:

SOC = (SOM x 0.58) x bulk density x layer thickness (cm)

A regression approach, based on radiocarbon data, was then used to calculate inert organic carbon (IOM):

$IOM = 0.049 \times SOC^{1.139}$

[1] Brookes, P.D., Stark, J.M., McInteer, B.B. and Preston, T. (1989). Diffusion method to prepare soil extracts for automated nitrogen-15 analysis. Soil Sci. Soc. Am. J. 53:1707-1711.

Total active carbon was then by subtracting IOM from total organic carbon. In this case SOC in the 0-50 cm soil layer at Pakhribas was 49.83 t ha^{-1}, IOM was 4.20 t ha^{-1} and total active carbon was 45.63 t C ha^{-1}.

Table 6. Input data for SUNDIAL.

Data Type	Required Input Variables	Useful Additional Data
Soil	Type: Sand, loam, clay, or texture class Depth (cm) Prev. Crop type Prev. Crop yield (t ha^{-1}) Period under grass	Total C (kg C ha^{-1}) mineral N on specified date to a certain depth (kg N ha^{-1} cm^{-1}) Minimum amount of N in soil Available water at field capacity ((mm water)(150 cm $soil)^{-1}$)
Weather	Total rainfall (mm/week) Total ET (mm/week) Average T (°C $week^{-1}$)	Soil Temperature on a specified date at a certain depth (°C) Soil water content on specified date at a certain depth (mm)
Crops and Fertilizer	Type Sowing Date (week) Harvest Date (week) Yield Number of fertilizer applications.. date, amount (kg N ha^{-1}), type (NO3, Urea, NH4)	N in crop at Harvest (kg N ha^{-1}) N in crop on specified date (kg N ha^{-1}) N in straw or haulms (kg N ha^{-1})
Organic Manures	Type Application Date (week) Amount (t ha^{-1})	Dry matter content (t ha^{-1}) Water content (t ha^{-1}) Total N in manure (kg N ha^{-1}) N available in first year (kg N ha^{-1}) Total C in manure (kg C ha^{-1})

Actual crop management practices for the different experimental treatments (outlined below) were used in the “set-up” files for the SUNDIAL run.

Observed yield data were used to set the expected yields for SUNDIAL, and data either from all plots or plots receiving ^{15}N-labelled fertilizer in 1998 were used to calculate crop N uptake values in separate model simulations.

5.6 FARMERS’ FIELD DAYS

These were held by scientists from ARS-Lumle and ARS-Pakhribas immediately prior to harvest of crops at all field sites. Groups of farmers (>20 people) visited the field sites and were asked to rank the different treatments by a variety of different scoring methods.

The field sites were also visited, and used as a resource for training and discussion by other NGOs. For example PLAN-International visited the field experiment at Sindhuwa.

Boards written in Nepali and English explained the layout of the trials and the levels of inputs.

5.7 WORKSHOP

A workshop, "Enhanced farmer livelihoods in the hills of Nepal through improved soil fertility" was held at the Dhulikhel Mountain Resort, Kathmandu on 25-26 July 1999.

This was attended by 46 delegates representing Nepal Agricultural Research Council scientists, scientists from Nepal and UK universities and research stations, staff from Helvetas and LIBIRD (NGOs), DFID representatives from HARP and government extension workers in the districts covering the field trials.

Having discussed the preliminary findings of this and related projects, delegates developed a prioritised list of researchable topics relating to soil fertility management for the mid-hills of Nepal and a list of preliminary recommendations.

5.8 SOCIO-ECONOMIC SURVEY

The following is a brief outline of the methodologies used in the survey of the four VDCs in which the field trials were established (Section 5.3.1). More detail is given in Appendix 6.

Four wards were selected from 4 Village Development Committees (VDCs) in three districts (Table 7).

Table 7. Sixteen selected wards (numbers given in table) from four VDCs for field survey.

Parbat District	Tanahu District	Dhankuta District	
Pakuwa VDC	Bhanu VDC	Pakhribas VDC	Murtidhunga VDC
1	1	3	1
4	4	6	2
5	7	7	5
6	8	8	9

Key Informant Surveys (KIS), Participatory Rural Appraisal (PRA) techniques and group discussions with farmers and household (HH) surveys were employed to collect the necessary data relating to the socio-economic context of the households in these areas and their management of soil fertility.

Two knowledgeable farmers in each ward (one male and one female) were interviewed in the KIS. It had originally been planned to involve a minimum of 12 farmers (6 of each sex) in each discussion group. The numbers of farmers of either gender participating in the group discussions in each ward are shown in Table 8.

The following techniques were used in the group discussion to generate a detailed picture of the villages:

1. Time line;
2. Agro-enterprise maps; and
3. Well-being ranking (based on the food self-sufficiency of each family expressed in months).

An unstructured questionnaire was used as a prompt during group discussions on the management of soil fertility.

For the household survey, households within a ward were allocated to one of four different categories based on food sufficiency for (1) 3 months or less, (2) 6 months, (3) 9 months and (4) 12 months or more. 32 respondents from within each category (16 male and 16 female) in each ward were then interviewed using a pre-tested questionnaire by 12 locally trained enumerators (6 male and 6 female) from each VDC. The questionnaire determined the land distribution of the farmer, the productivity of commonly grown crops, the use of fertilizer and manure and any changes, the numbers of livestock, the availability of labour, details of income and expenditure, and practices relating to the management of soil fertility.

Table 8. Numbers of participants in group discussion in different wards.

VDC	**Ward Number**	**Participants in group discussion**		
		Male	**Female**	**Total**
Pakuwa	1	11	3	14
	4	4	3	7
	5	7	4	11
	6	8	5	13
Bhanu	1	16	8	24
	4	7	3	10
	7	13	9	22
	8	12	5	17
Pakhribas	3	11	5	16
	6	7	4	11
	7	12	6	18
	8	10	6	16
Murtidhunga	1	6	9	15
	2	15	5	20
	5	7	4	11
	9	14	6	20

5.9 ECONOMIC ANALYSIS OF TRIAL RESULTS

Economic analysis of the trial using a partial budget approach (Table 9) was used to compare the different treatments and to provide a basis for the development of recommendations.

The impact of providing nutrients (the net benefit) is calculated by subtracting the total costs from the total benefits (B-C). If the benefits are greater than the costs then the change is likely to be advantageous, and vice versa. The partial budget used costs faced by the farmer (see Appendix 4 for details of these and of the subsequent analysis, for data from the first cropping cycle).

Table 9. Partial budget analysis comparing use of organic and inorganic fertilizer sources with no nutrients in a two crop rotation (Crop1, Crop2).

BENEFITS		**COSTS**	
Increased income		*Decreased income*	
Increased yield of grain (Crop1) x price	B1		
Increased yield of straw (Crop1) x price	B2	if any	C1
Increased yield of grain (Crop2) x price	B3		
Increased yield of straw (Crop2) x price	B4		
Total increase in benefits	*BI*	*Total decrease in benefits*	*CI*
Decreased costs		*Increased costs*	
		Quantity of manure x price	C2
if any	B5	Quantity of fertilizer x price	C3
		Labour required ■ making manure ■ transporting and spreading manure ■ transporting and spreading fertilizer ■ additional labour for harvesting	C4
Total reduction in costs	*BII*	*Total increase in costs*	*CII*
Total Benefits	**BI+BII**	**Total Costs**	**CI+CII**

6 OUTPUTS

6.1 OUTPUT 1: A series of systems-based nutrient balances for the major farming systems in the mid-hills of Nepal.

A survey of the literature suggested that a hypothetical household in the mid-hills of Nepal had the characteristics specified in Table 10. For more detail on the derivation of this household and its use in the construction of a nutrient balance see Appendix 2.

Table 10. Summary of characteristics selected from the available literature to define a hypothetical household in the mid-hills of Nepal and subsequently used for calculating the N budget.

Characteristic		Values	
Total Land Area (ha)		1.0	
Pieces of land		4	
Bari:Khet		2:1	
Trees		50-80	
Number of Animals		Buffalo	2
		Bullock (Ox)	2
		Cows	1
		Goat	3
		Chicken	6
		Average Grain Yield (kg/ha)	Average Straw Yield (kg/ha)
Crops	Maize (*Zea mays*)	2000	3000
	Finger millet (*Eleusine coracana*)	1160	1740
	Rice (*Oryza sativa*)	2000	3000
	Wheat (*Triticum aestivum*)	2500	3750

Figure 6 shows the calculated N fluxes for this household (more details are given in Appendix 2). It shows that the system is in balance with respect to N with inputs across the boundary of about 26 kg N a^{-1} (mainly in fertilizer) and losses, excluding gases, of about 60 kg N a^{-1} (mainly in crop removal). Tree fodder and grasses are a major source of N (80 kg N a^{-1}) to the household. A major pathway for the flow of N within the system is via the forage fed to livestock, and the subsequent application of manure to crops. Typically, manure and compost supply 100 kg N to crops (4 times that supplied by fertilizer) and produce crops with a N content in grains of 36 kg N. The N losses via soil erosion are shown to be small but losses via leaching and gases are largely unquantified. It is concluded that the use of tree fodder and forage from forest areas and grasses from terrace risers as animal feed ensures a net movement of N from non-agricultural land to agricultural land. The magnitude of this movement is not known, because the quantities of vegetation gathered from inside and outside the household boundaries are not known.

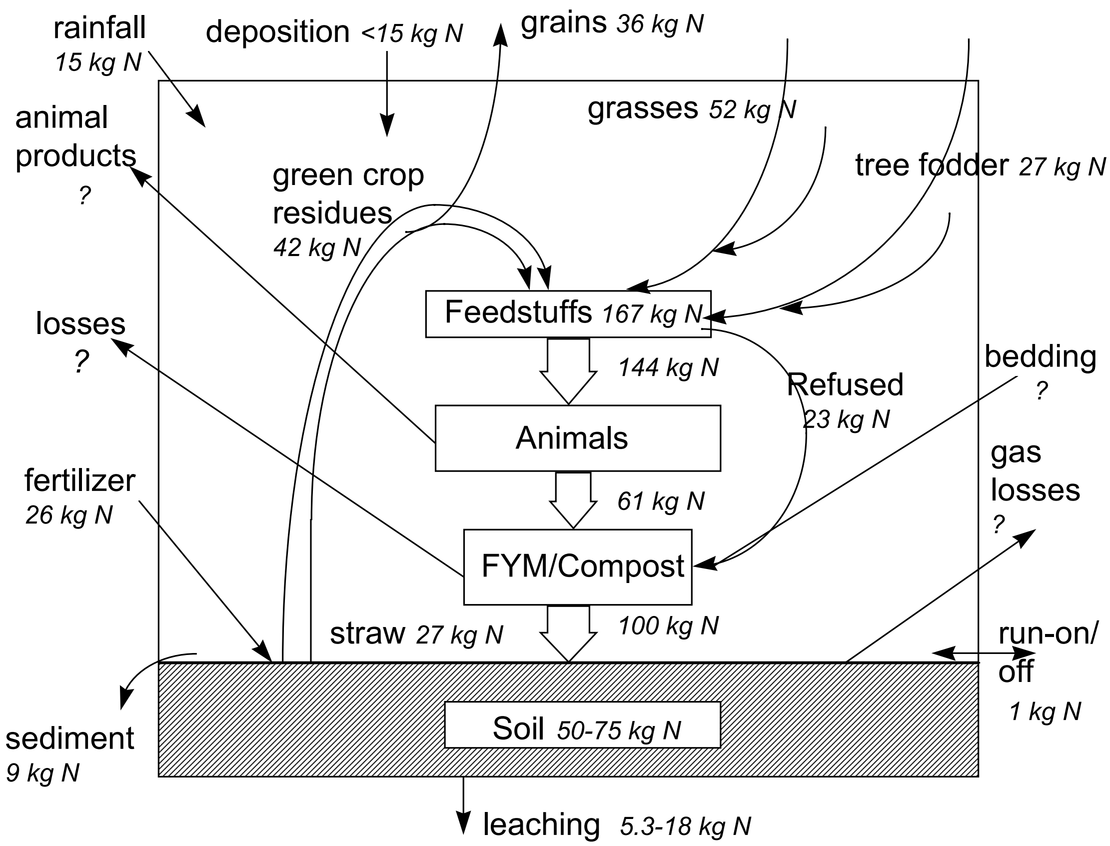


Figure 6. A flow diagram of N for a hypothetical household in the mid-hills of Nepal, showing the amounts of N flowing through different pathways. ? represent unquantified pathways.

Further analysis of some of the unquantified fluxes (*e.g.* rates of N fixation by algae) and the separation of fluxes internal to the household from those across the household boundary are given in Appendix 3.

6.2 OUTPUT 2: Quantitative exposition of the effects of manure and fertilizers on long-term fertility of soils in mid-hills.

6.2.1 Characterisation of baseline soil samples

Soils from each site are described in Table 11. They are moderately acidic and with the exception on Dordor Tar dominated by sand and silt.

Table 11. Some chemical indicators of soil fertility and particle size analysis of the 0-25cm soil layer from the experimental field sites. Samples were taken in April 1997 before experimentation began. Mean values of 28 samples are shown. Data are available for the other layers to 1 m but are not shown.

Site	Total N (%)	Avail. P (mg/kg)	Organic Carbon (%)	pH	Sand (%)	Silt (%)	Clay (%)
Dordor Guan	0.078	31.39	0.82	5.39	30	41	29
Pakuwa	0.113	36.14	0.95	5.88	n/a	n/a	n/a
Chambas	0.105	7.18	0.92	6.39	n/a	n/a	n/a
Kholitar	0.094	12.87	1.62	5.28	57	32	11
Pakhribas	0.080	20.84	1.32	5.98	62	26	12
Dordor Tar	0.136	4.25	1.08	5.68	18	32	50

6.2.2 Crop Yields

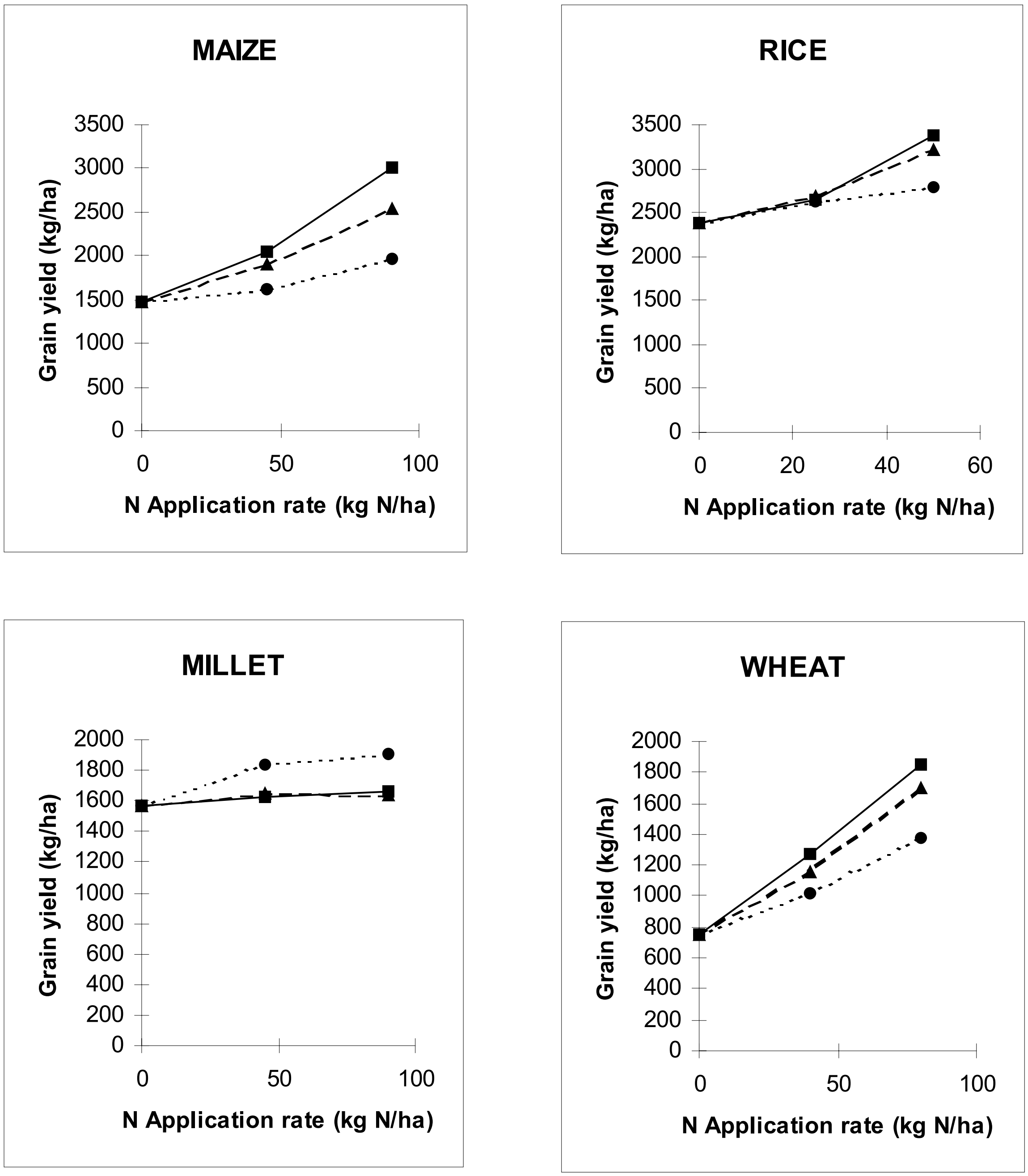
Any input generally increased yield (Fig. 7; Table 12). Chemical fertilizer had the largest impact on grain yield in all crops to which it was applied. The effects were largest when fertilizer was applied alone rather than in combination with manure. Sole applications of manure had the least effect on the crop to which they were applied, but the largest residual impact. Manure applications to maize increased the grain yield of millet, whereas chemical fertilizer had no residual effect.

Yields of the three major cereal crops (maize, rice and wheat) were all increased by more than 500 kg ha^{-1} following the application of chemical fertilizer. This contrasts with the data presented in Appendix 5 which report the grain yields from of a long-term field trial at ARS-Pakhribas which received applications of manure, fertilizer or combinations of the two. In that experiment yields were greater following the application of manure rather than fertilizer, for all crops except wheat. See Appendix 5 for more details.

Table 12. Average increase in yield (kg/ha) following the application of fertilizer, manure or a combination of fertilizer plus manure compared with zero inputs to 5 crops grown in the mid-hills of Nepal.

	Maize	Millet	Rice	Wheat	Upland Rice
Fertilizer vs Zero Input	1059	78	625	805	399
Manure vs Zero Input	319	311	319	442	231
Fertilizer +	755	78	558	674	162

Manure vs
Zero Input



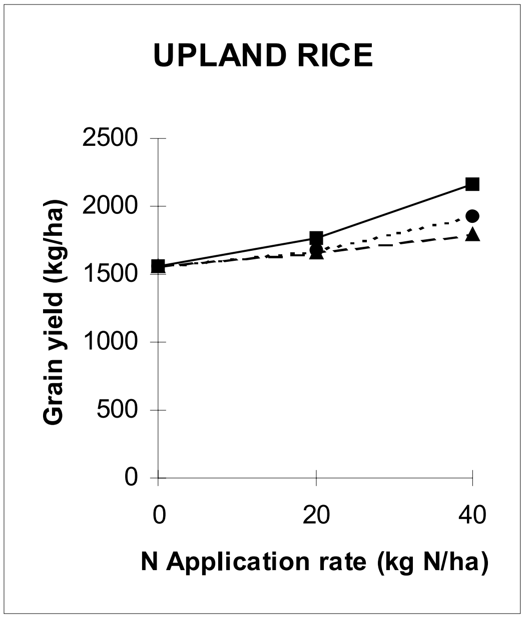

UPLAND RICE
Grain yield (kg/ha)
2500
2000
1500
1000
500
0
0
20
40
N Application rate (kg N/ha)

Figure 7. Grain yields (kg/ha) of maize, millet, rice, wheat and upland rice averaged over 2 years (except upland rice which was averaged over 3 years) and all possible locations (2 for maize and millet, 3 for rice and wheat and 1 for upland rice). N was applied as fertilizer (squares, solid lines), manure (circles, dotted lines) and fertilizer plus manure (triangles, dashed lines).

6.2.3 Nutrient off-takes in crop materials

Nutrient losses were affected more by location and crop type than by treatment (Table 13). N losses were greatest for rice grown at Chambas and maize grown at Pakhribas, and least for millet grown at Dordor Gaun. Losses of P were least for wheat, particularly at Kholitar and Pakuwa, and greatest for rice. More K was removed than either N or P. Greatest losses of K occurred for rice at Chambas.

6.2.4 Nitrogen fixation by blackgram

On average over two years blackgram fixed approximately 54 % of its shoot N content (Table 14). This amounted to between 3 and 8 kg N ha^{-1} (Table 14).

6.2.5 Recovery of ^{15}N-labelled urea applied as a top dressing to rain-fed crops

Less than 25 % of the N fertilizer applied as a top dressing was recovered in the crops to which it was applied (Table 15). Generally, two-thirds of this was found in the grain, with the remainder being found in the stover/straw. Most of the N in a crop therefore came from unlabelled nitrogen mineralized either from the soil N pool or from manure, if it were applied (Treatments 4 and 7).

A larger percentage of the applied fertilizer was found in the soil at harvest of the maize than in the crop (Table 15). (Soil samples were not taken from the upland rice because the soil was too wet to be adequately sieved and mixed prior to sub-sampling; see activities). More than half of the fertilizer recovered in the soil was found below 20cm (Table 15) implying rapid movement and immobilization of inorganic N forms.

Table 13. Total amount over two years of N, P and K (kg ha^{-1}) removed in grain and straw in crops of maize, millet, rice, wheat and upland rice grown at different sites in the mid-hills of Nepal and subject to different nutrient application regimes.

Maize	**N** **Dordor Gaun**	**Pakhri-bas**	**P** **Dordor Gaun**	**Pakhri-bas**	**K** **Dordor Gaun**	**Pakhri-bas**
Zero-input	42	121	29	17	30	114
Fertilizer (90 kg N ha^{-1})	137	170	67	20	76	159
Manure (90 kg N ha^{-1})	64	123	41	24	50	165
Combination (90 kg N ha^{-1})	99	142	49	18	63	179
Fertilizer (45 kg N ha^{-1})	68	144	41	21	39	156
Manure (45 kg N ha^{-1})	51	118	37	21	42	118
Combination (45 kg N ha^{-1})	59	136	32	23	35	132

Millet	**Dordor Gaun**	**Pakhri-bas**	**Dordor Gaun**	**Pakhri-bas**	**Dordor Gaun**	**Pakhri-bas**
Zero-input	40	71	26	31	93	156
Fertilizer (90 kg N ha^{-1})	44	71	40	36	99	165
Manure (90 kg N ha^{-1})	52	77	36	40	125	194
Combination (90 kg N ha^{-1})	44	78	32	32	108	165
Fertilizer (45 kg N ha^{-1})	40	71	26	29	86	159
Manure (45 kg N ha^{-1})	48	80	35	35	118	155
Combination (45 kg N ha^{-1})	45	82	32	34	105	159

Rice	**Chambas**	**Pakuwa**	**Chambas**	**Pakuwa**	**Chambas**	**Pakuwa**
Zero-input	121	65	42	44	177	92
Fertilizer (50 kg N ha^{-1})	174	105	61	66	273	154
Manure (50 kg N ha^{-1})	151	84	48	54	242	138
Combination (50 kg N ha^{-1})	154	100	55	58	260	144

Fertilizer (25 kg N ha^{-1})	138	80	51	49	212	120
Manure (25 kg N ha^{-1})	122	82	43	34	205	105
Combination (25 kg N ha^{-1})	134	71	44	41	238	104

Wheat	**Chambas**	**Pakuwa**	**Chambas**	**Pakuwa**	**Chambas**	**Pakuwa**
Zero-input	41	26	13	12	37	26
Fertilizer (80 kg N ha^{-1})	125	62	36	19	124	63
Manure (80 kg N ha^{-1})	66	49	20	17	64	48
Combination (80 kg N ha^{-1})	72	60	24	19	84	56
Fertilizer (40 kg N ha^{-1})	72	44	22	15	71	42
Manure (40 kg N ha^{-1})	47	42	25	15	49	51
Combination (40 kg N ha^{-1})	51	44	27	16	60	45

Upland Rice	**Dordor Tar**	**Kholitar***	**Dordor Tar**	**Kholitar**	**Dordor Tar**	**Kholitar**
Zero-input	55	68	35	12	127	112
Fertilizer (40 kg N ha^{-1})	88	132	47	22	164	250
Manure (40 kg N ha^{-1})	62	76	35	13	131	152
Combination (40 kg N ha^{-1})	69	116	37	21	128	237
Fertilizer (20 kg N ha^{-1})	88	93	44	16	147	151
Manure (20 kg N ha^{-1})	68	79	34	14	114	153
Combination	56	100	35	16	126	187

(20 kg N ha^{-1})	

[*]Kholitar at ARS-Pakhribas grew rice rather than upland rice.

Table 14. Proportion of N fixed by blackgram estimated by the isotope dilution technique using Niger as a reference crop, sampled at two different stages in 1997, and in 1998 from plots amended with different forms and rates of nutrients applied to the preceding upland rice crop. The average amount of N fixed and total shoot N content for the blackgram crops are also shown.

Year	Treatment	P_{fix}	Amount N fixed (kg/ha)	Shoot N content (kg/ha)
1997	Physiological Maturity	0.53	4.5	8.5
	Final Harvest	0.67	3.3	4.9
1998	T2	0.47	6.8	13.1
	T4	0.45	3.7	9.2
	T5	0.5	6.8	13.3
	T7	0.64	8.3	12.9

A large percentage of the N fertilizer applied was unaccounted for either in the crop or in the 0-60cm soil layer (Table 15). This N fertilizer may be lost gaseously by denitrification or in drainage water. The occurrence of considerable amounts of ^{15}N-labelled fertilizer makes the latter hypothesis credible.

Table 15. Percentage recovery in crop parts and different soil layers at harvest of ^{15}N-labelled urea applied at two different rates either alone (T2 and T5) or in combination with manure (T4 and T7) to maize and upland rice in June 1998. Soils from Dordor Tar were not sampled at final harvest.

Crop	Treatment	Grain	Straw	0-20 cm	20-40 cm	40-60 cm	Crop+ Soil	Unaccounted for
Maize (Dordor Gaun)	2	15	7	9	11	8	50	50
	4	9	9	24	43	16	101	0
	5	10	8	27	21	25	91	9
	7	13	8	39	30	28	118	0
Maize (Pakhribas)	2	11	4	19	8	11	53	47
	4	10	6	4	22	17	59	41
	5	9	4	30	27	8	78	22
	7	8	5	19	40	16	88	12
Upland Rice	2	15	8					
	4	8	5					
	5	10	5					

	7	13	7

6.2.6 Recovery of ^{15}N-labelled urea applied as a top dressing to a preceding crop

Generally less than 2 % of the N fertilizer applied to a preceding crop was recovered in the subsequent crop (Table 16) suggesting that immobilized fertilizer N is not rapidly re-mineralized. Much of the recovered fertilizer therefore remains in the soil (Table 16).

Discrepancies in the percentage of applied N fertilizer recovered in the soils between the two harvest dates may be attributed to the spatial variation in total soil N content.

Table 16. Percentage recovery in crop parts and different soil layers of ^{15}N-labelled urea applied to a preceding crop.

Crop	Treatment	Grain	Straw	0-20 cm	20-40 cm	40-60 cm	Soil	Crop+ Soil
Millet (Dordor Gaun)	2	0.7	0.6	21	20	17	58	59.3
	4	1.0	0.8	34	21	24	79	80.8
	5	0.9	0.9	30	23	21	74	75.8
	7	1.5	1.1	56	39	34	129	131.6
Millet (Pakhribas)	2	0.8	0.6	16	6	9	31	32.4
	4	0.6	0.9	33	13	25	71	72.5
	5	1.1	0.7	26	23	23	72	73.8
	7	1.3	0.7	42	28	32	102	104
Blackgram	2	0.1	0.2					
	4	0.1	0.1					
	5	0.2	0.2					
	7	0.1	0.3					

6.2.7 Short-term recovery of ^{15}N-labelled fertilizer

6.2.7.1 Maize

Urea was rapidly hydrolysed to ammonium (Fig. 8) and immobilized in organic N forms, which finally accounted for approximately 40 % of the applied N fertilizer. Most of the fertilizer in mineral N forms was found as ammonium rather than nitrate and in the upper (0-5 cm) layer rather than the lower layers (Fig. 8). Overall recovery of N fertilizer declined from >80 % on day 1 after application to approximately 50 % one week later (Fig. 8).

6.2.7.2 Rice

Total recovery of applied fertilizer exceeded 70 % (Fig. 9). Urea was rapidly hydrolysed to ammonium which accounted for more than 40 % of the applied fertilizer by day 3 (Fig. 9). Recovery of fertilizer as nitrate was low (<2 %; Fig. 9). By day 3 after application >30 % of the applied fertilizer had been immobilized into organic N forms. Flooding appeared to have little effect on the fate of applied fertilizer, perhaps because so little was present as nitrate.

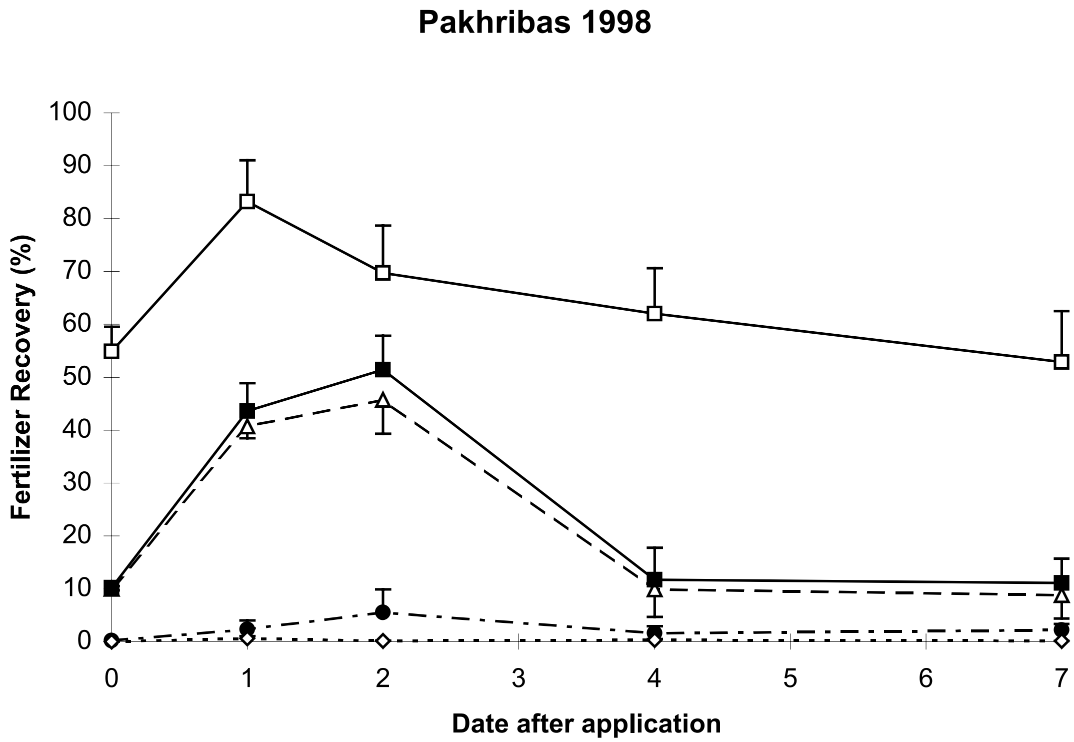
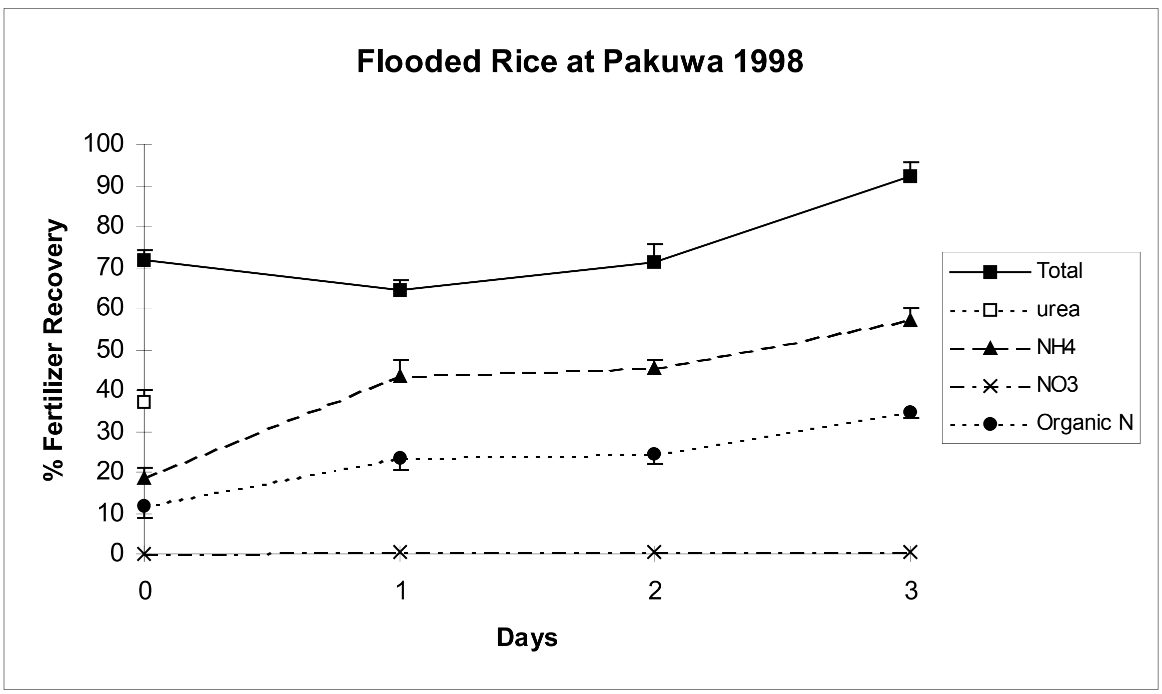


Figure 8. Mean percentage recovery in mineral N forms in three soil layers (open triangles, 0-5 cm; solid circles, 5-15 cm ; open diamonds, 15-25 cm) of ^{15}N-labelled urea applied to small cores at Pakhribas in June 1998. Solid squares represent the recovery in the total mineral N pool while open squares represent the recovery in the total soil N pool. Bars represent a standard error of the mean.


Flooded Rice at Pakuwa 1998
100
90
80
70
60
50
40
30
20
10
0
% Fertilizer Recovery
0
1
2
3
Days
Total
urea
NH4
NO3
Organic N

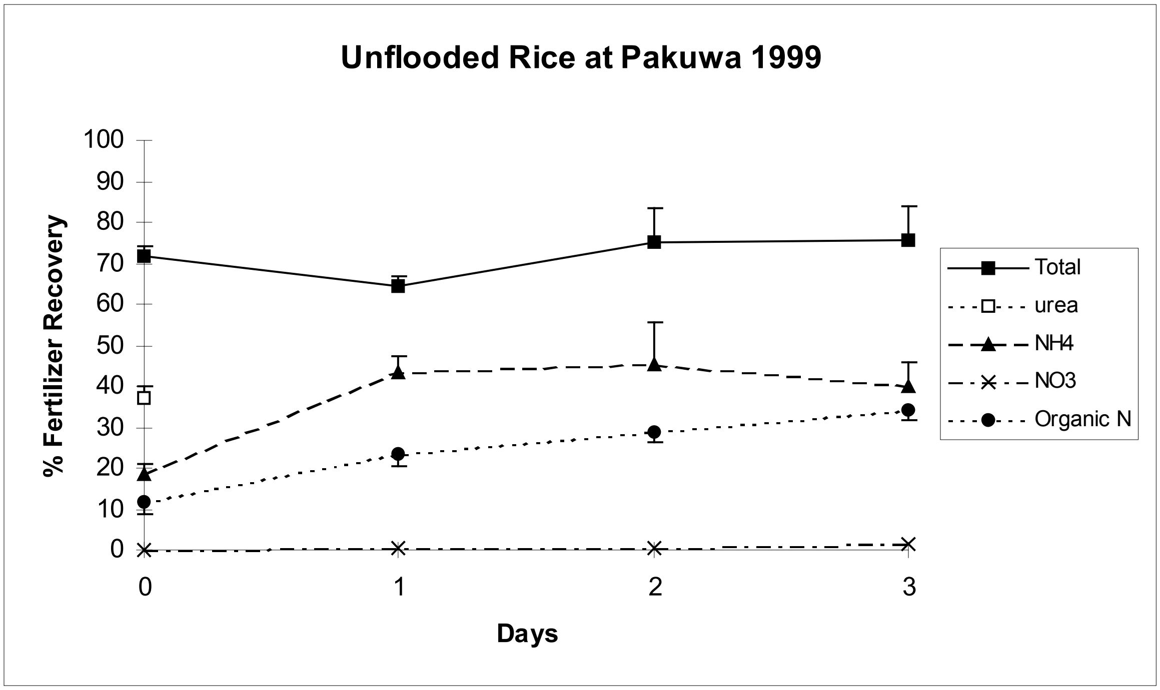
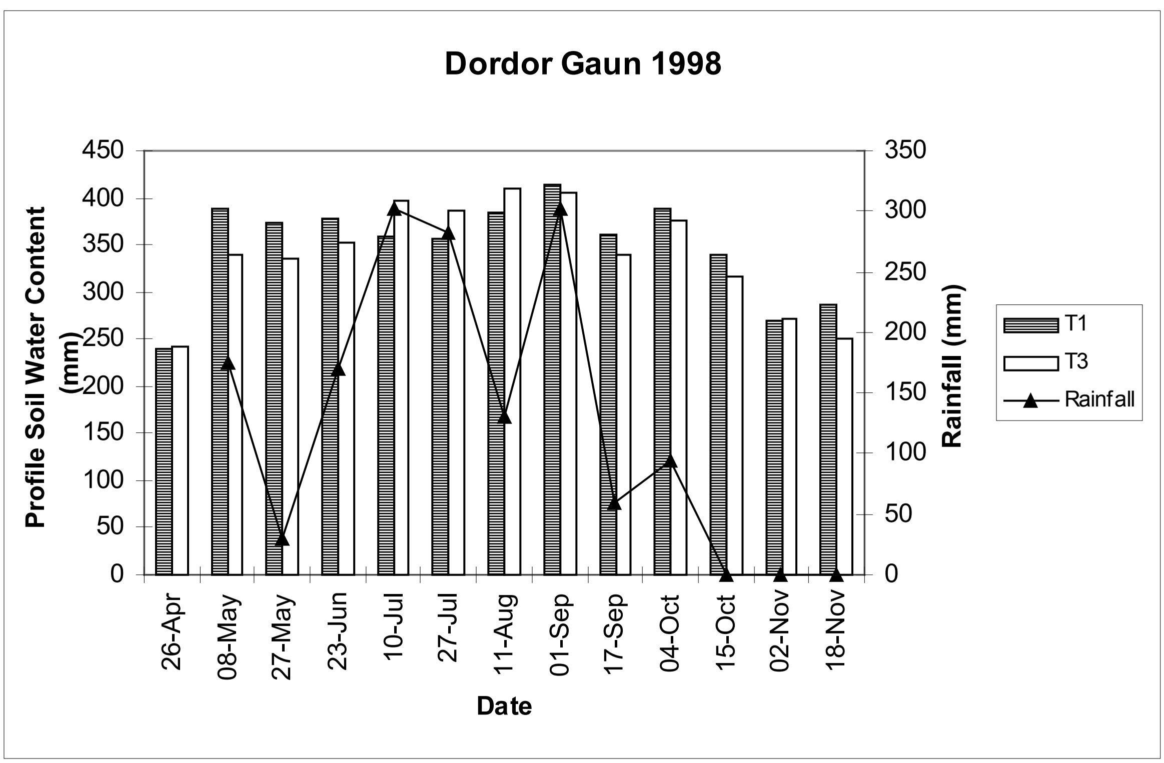


Figure 9. Percentage recovery in different soil N pools of ^{15}N-labelled urea fertilizer applied to 15 cm deep cores at Pakuwa in August 1998. Soils were drained prior to application and re-flooded after the sampling on day 1. Bars represent a standard error of the mean.



Dordor Gaun 1998
Profile Soil Water Content (mm)
Rainfall (mm)
Date
T1
T3
Rainfall
0
50
100
150
200
250
300
350
400
450
26-Apr
08-May
27-May
23-Jun
10-Jul
27-Jul
11-Aug
01-Sep
17-Sep
04-Oct
15-Oct
02-Nov
18-Nov

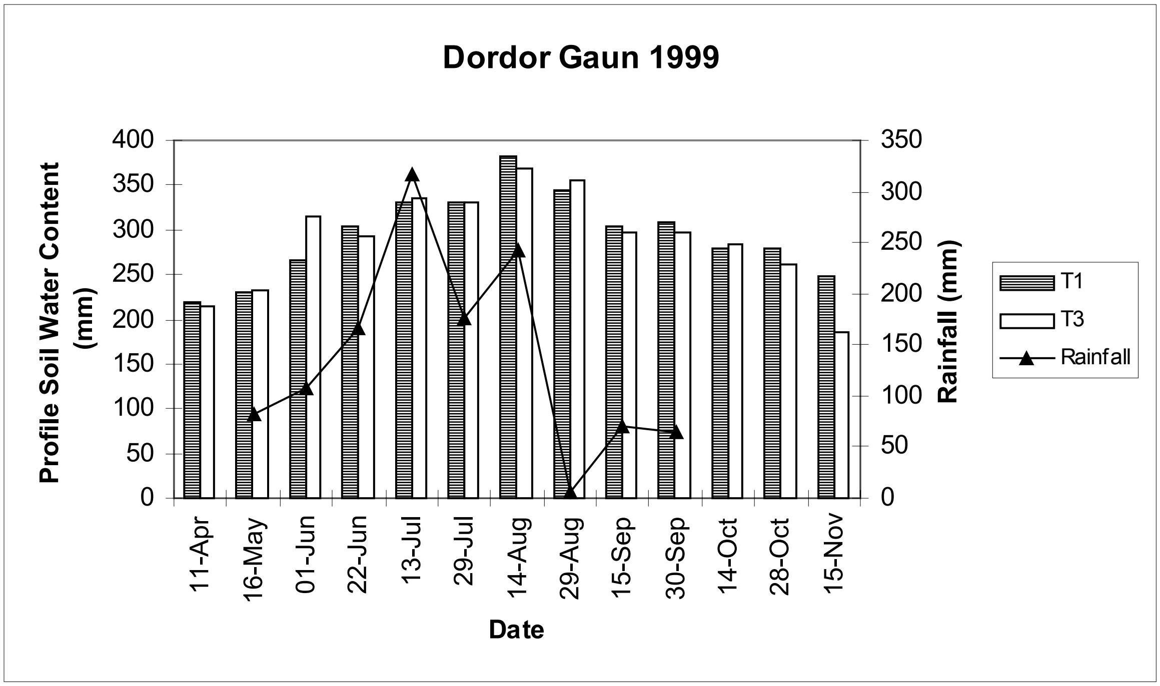


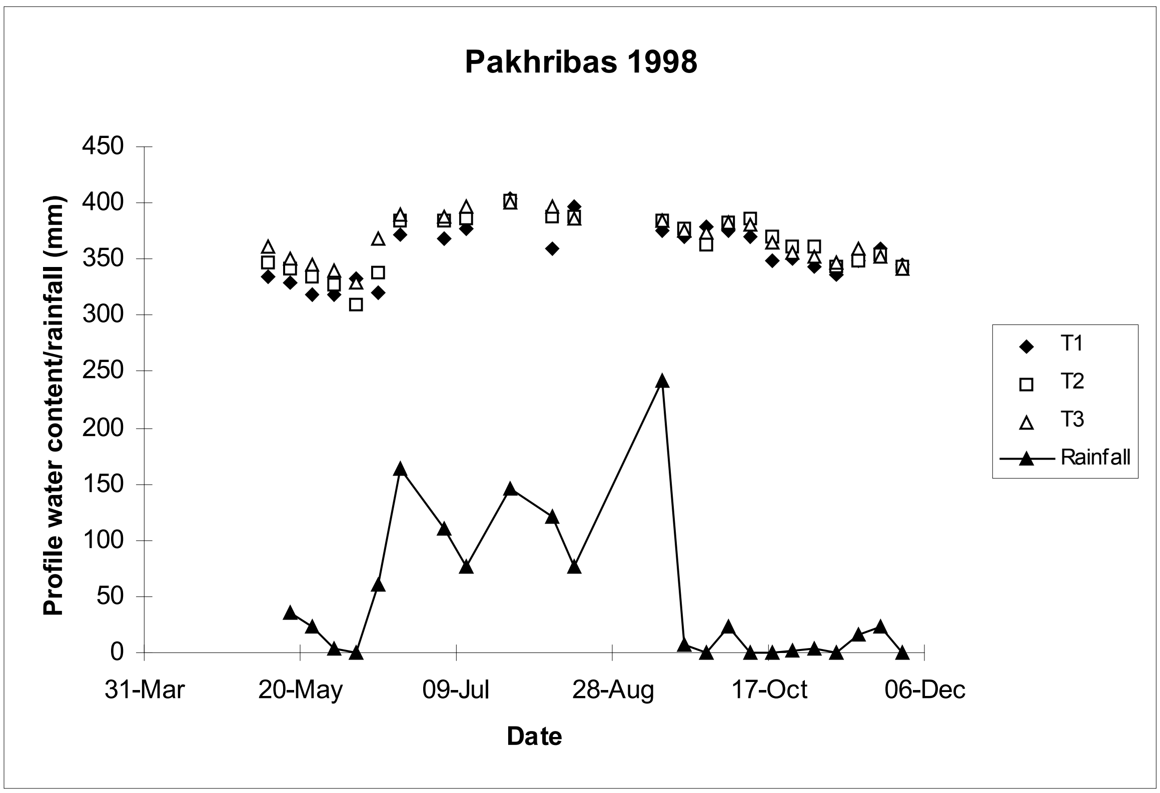
Figure 10. Average depth of water stored in a 95 cm soil profile at Dordor Gaun in 1998 and 1998. Plots were either unfertilized (T1) or received manure at a rate of 90 kg N ha^{-1} (T3). Rainfall volumes between dates of theta probe measurements are shown.

6.2.8 Profile Soil Water Contents

Profile water content (to 90 cm depth) at Dordor Gaun increased from less than 250 mm to more than 350 mm as the monsoon season progressed, and then declined as rainfall declined. There was little difference in water content between the 2 treatments (Fig. 10).

At Pakhribas the increase in soil moisture content was less than at Dordor Gaun, increasing from 350 mm to 400 mm. Again there was little difference in water content between the treatments (Fig. 11).

Rainfall exceeded the storage capacity of the soil giving rise to an excess of water which was lost either by drainage or by evapotranspiration (Figs. 12 and 13). The smaller losses in September to November at both sites are likely to be attributable to evaporation from the soil surface and transpiration from the millet crops. The larger losses in July and August, when potential evaporation is approximately 1 mm per day, are mainly attributable to drainage.



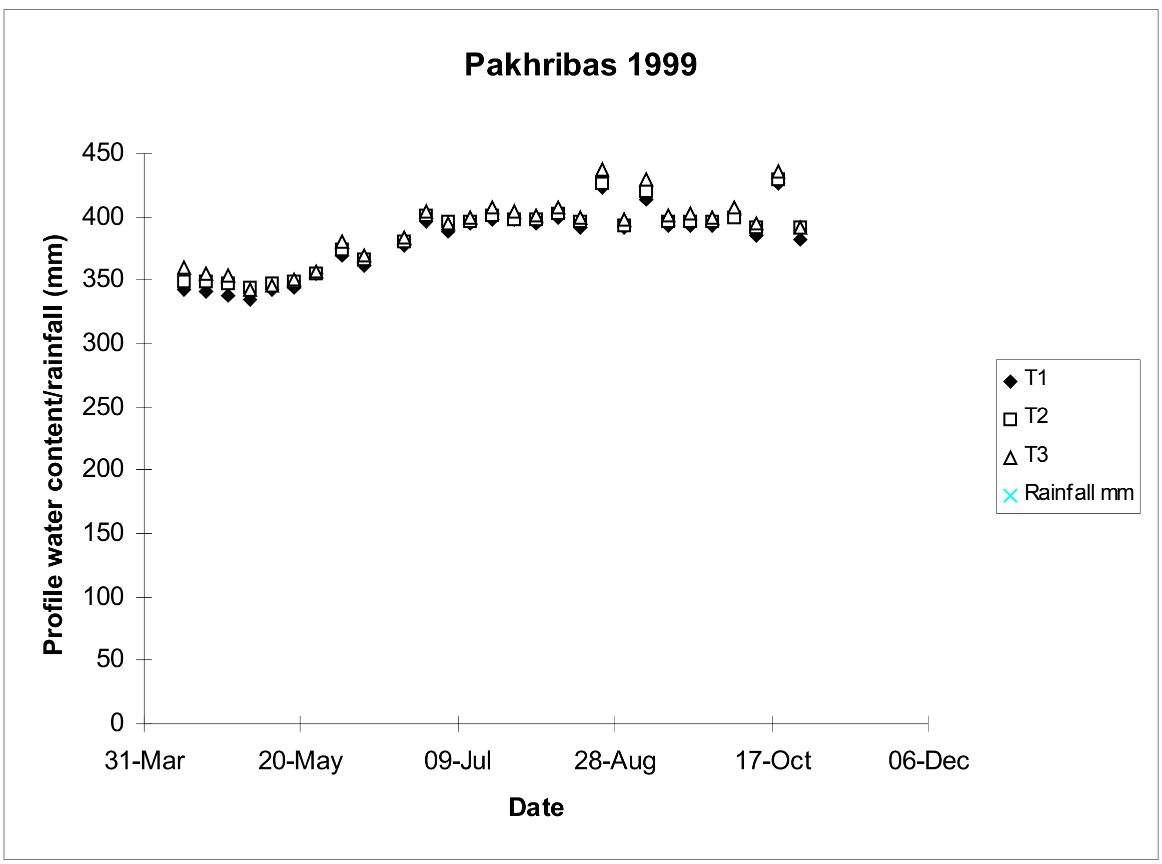

Pakhribas 1999
Profile water content/rainfall (mm)
450
400
350
300
250
200
150
100
50
0
31-Mar
20-May
09-Jul
28-Aug
17-Oct
06-Dec
Date
T1
T2
T3
Rainfall mm

Figure 11. Average depth of water stored in a 95 cm soil profile at Pakhribas in 1998 and 1998. Plots were unfertilized (T1) or received fertilizer (T2) or manure (T3) at a rate of 90 kg N ha^{-1}. Rainfall volumes between dates of theta probe measurements are shown.

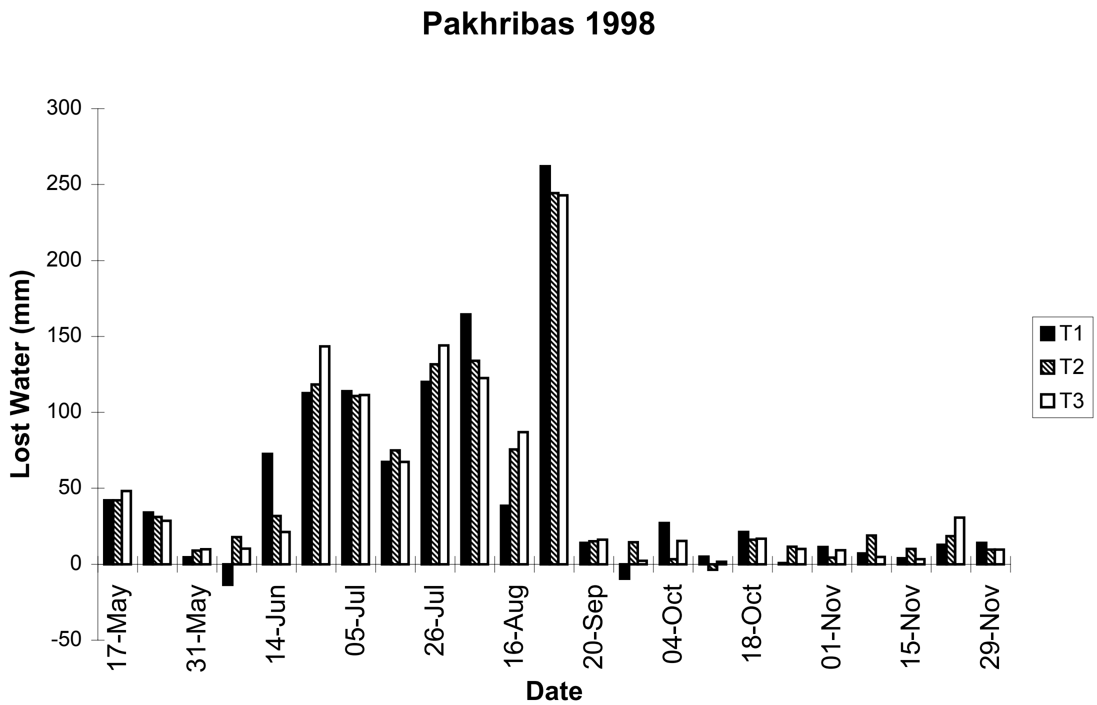
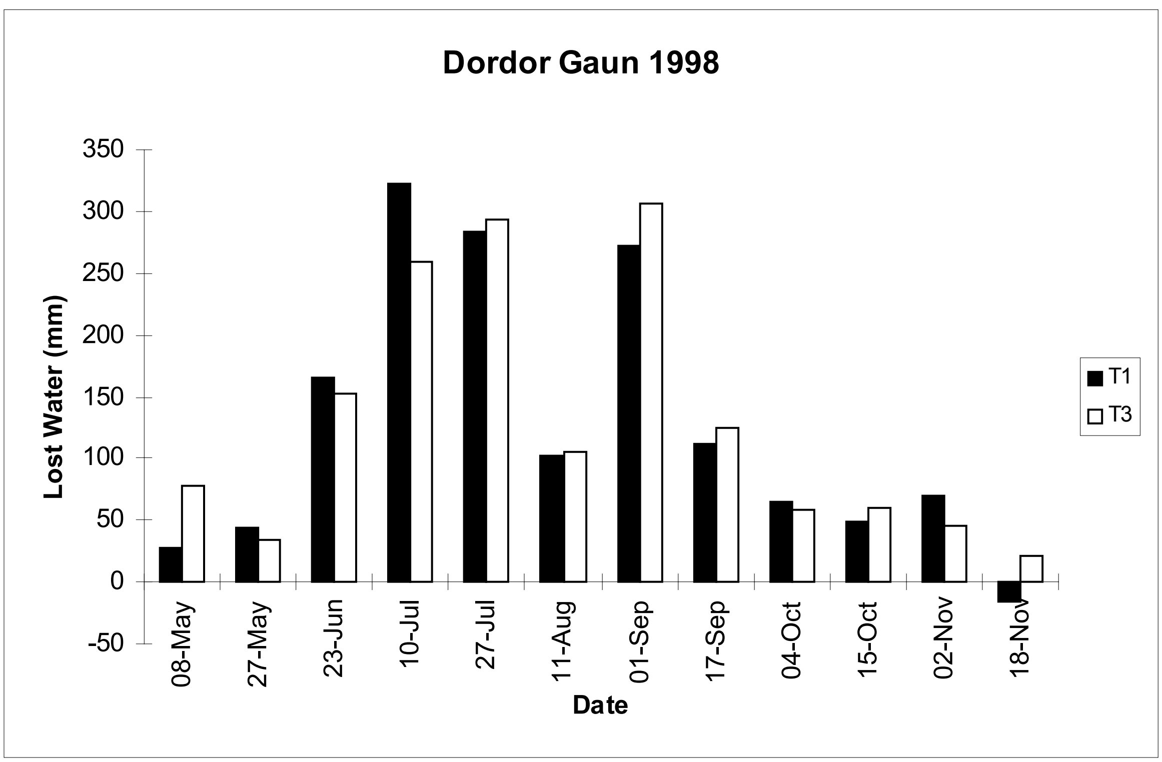


Figure 12. Average depth of water "lost" either through ET or drainage for Pakhribas in 1998. T1 was the zero-input, T2 received 90 kg N ha^{-1} as fertilizer, T3 received 90 kg N ha^{-1} as manure.



Dordor Gaun 1998
350
300
250
200
150
100
50
0
-50
Lost Water (mm)
08-May
27-May
23-Jun
10-Jul
27-Jul
11-Aug
01-Sep
17-Sep
04-Oct
15-Oct
02-Nov
18-Nov
Date
T1
T3

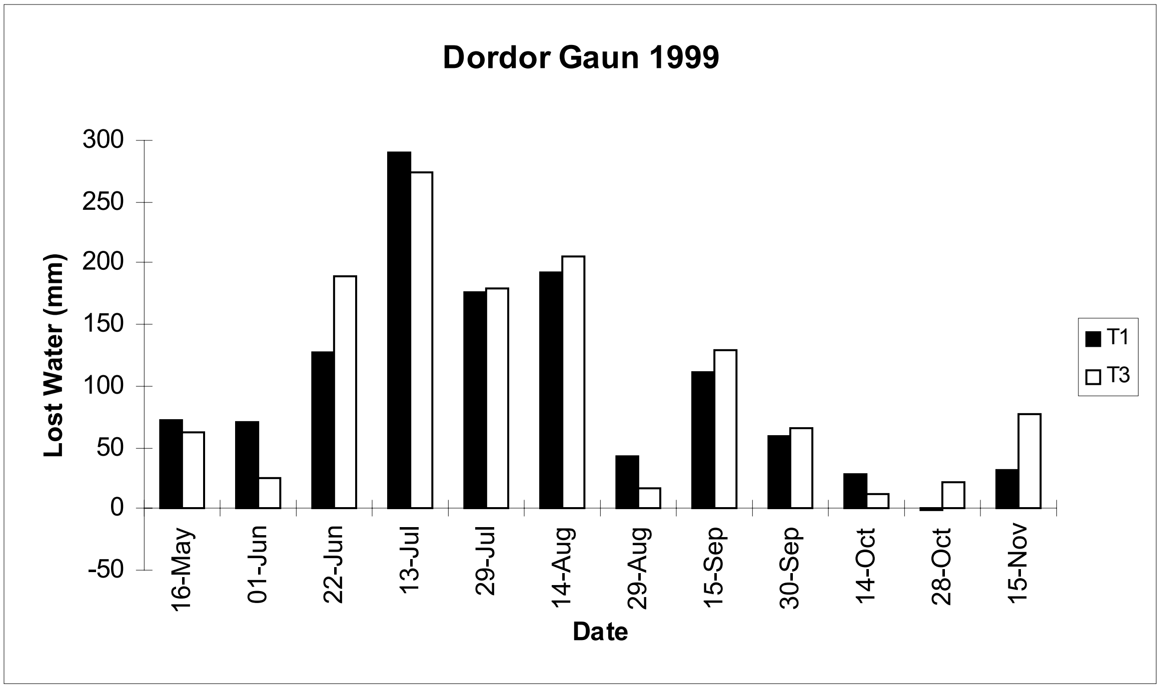
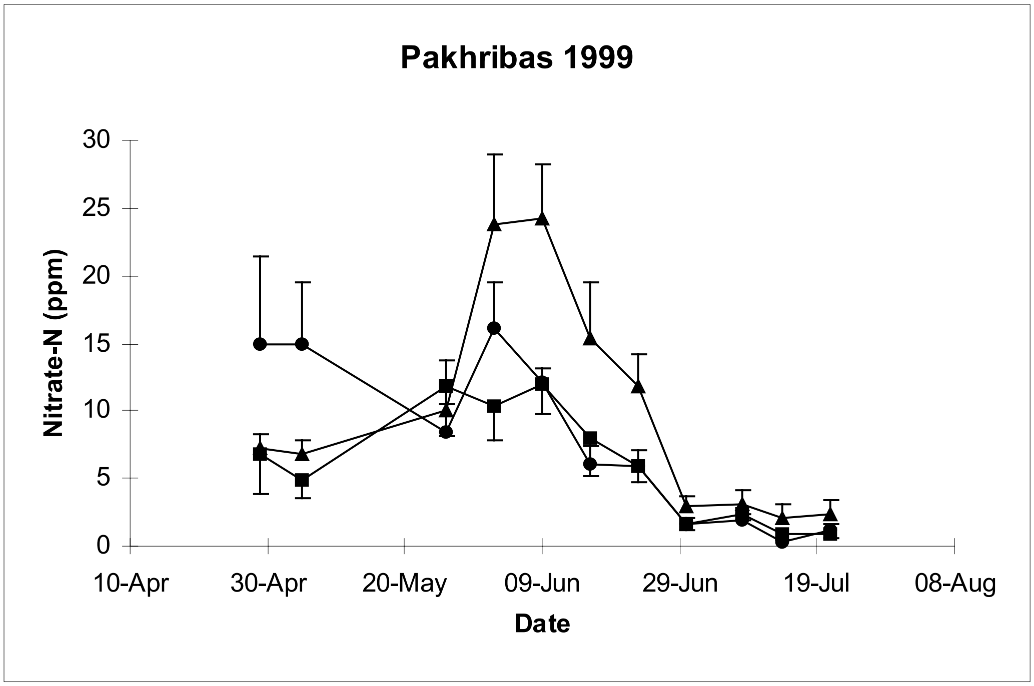


Figure 13. Average depth of water "lost" either through ET or drainage for Dordor Gaun in 1998 and 1999. T1 was the zero-input, and T3 received 90 kg N ha^{-1} as manure.

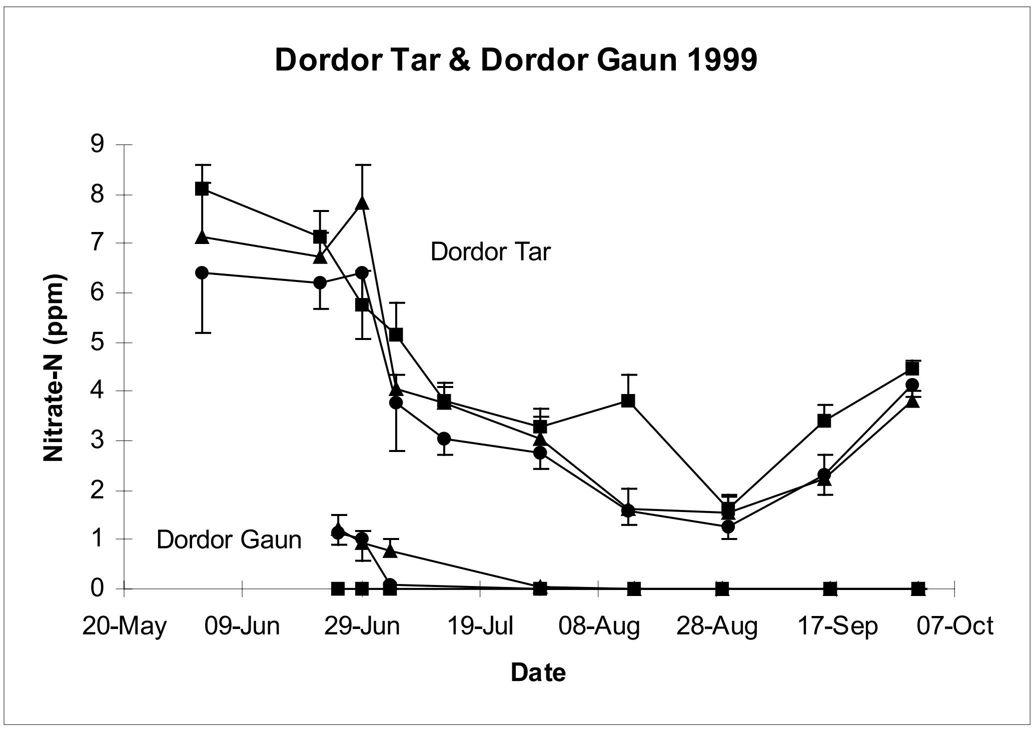
6.2.9 Nitrate concentrations in leachate.

There was no measurable ammonium-N in the ceramic cups at Dordor Gaun and Pakhribas in either year, however there were traces (< 0.1 ppm) of ammonium-N in the leachate from Dordor Tar.

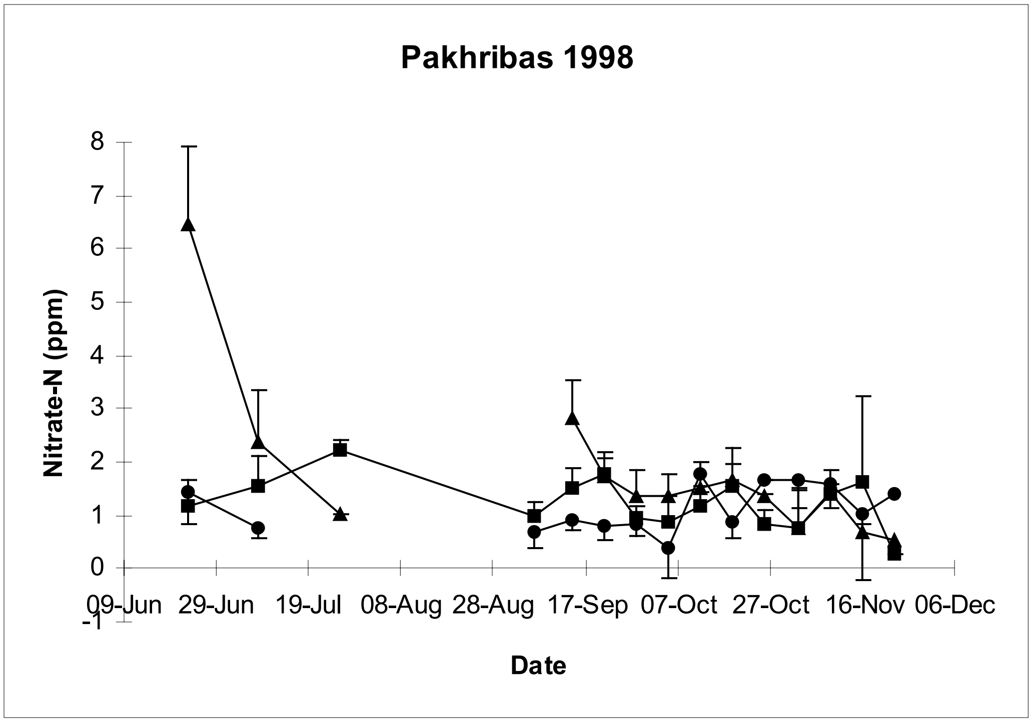
Concentrations of nitrate-N were generally high at Pakhribas and Dordor Gaun until late June/early July, when they fell to low levels (<3 ppm; Fig. 14). Concentrations of nitrate-N at Dordor Tar did not show such extreme temporal patterns remaining between 2 and 10 ppm nitrate-N throughout the season (Fig. 14).



Pakhribas 1999
Nitrate-N (ppm)
30
25
20
15
10
5
0
10-Apr
30-Apr
20-May
09-Jun
29-Jun
19-Jul
08-Aug
Date



Dordor Tar & Dordor Gaun 1999
Dordor Tar
Dordor Gaun
Nitrate-N (ppm)
9
8
7
6
5
4
3
2
1
0
20-May
09-Jun
29-Jun
19-Jul
08-Aug
28-Aug
17-Sep
07-Oct
Date



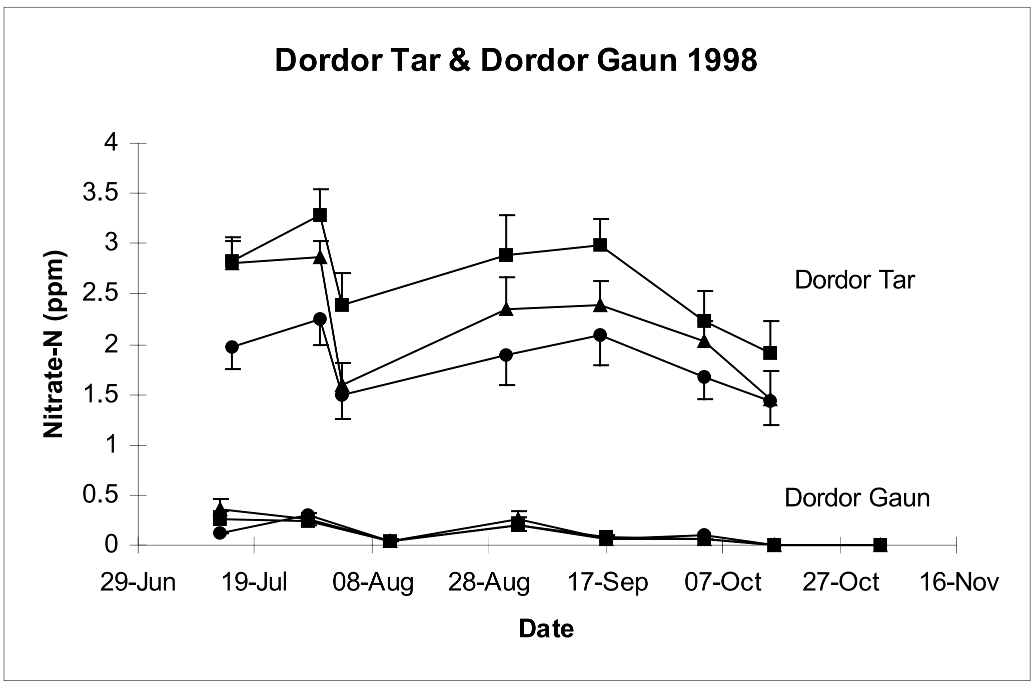


Figure 14. Changes in nitrate-N concentration (ppm) in soil solution samples collected using ceramic cups installed to 90 cm depth at Pakhribas and Dordor Gaun and to 75 cm depth at Dordor Tar during two consecutive seasons.

6.2.10 Losses of nutrients from irrigated paddies

The volume of water flowing across a terrace in 1 h at Pakuwa was equivalent to the volume of water contained in the terrace, so that in a 10 hour irrigation period the water in a terrace may turn over 10 times.

There was no detectable phosphorus.

Concentrations of nitrate and potassium in the irrigation water were small (<0.1 ppm). However, the volume of water flowing ensured that amounts of nitrate and potassium lost from the terrace were approximately 0.2-0.5 kg ha^{-1} d^{-1} (Table 17).

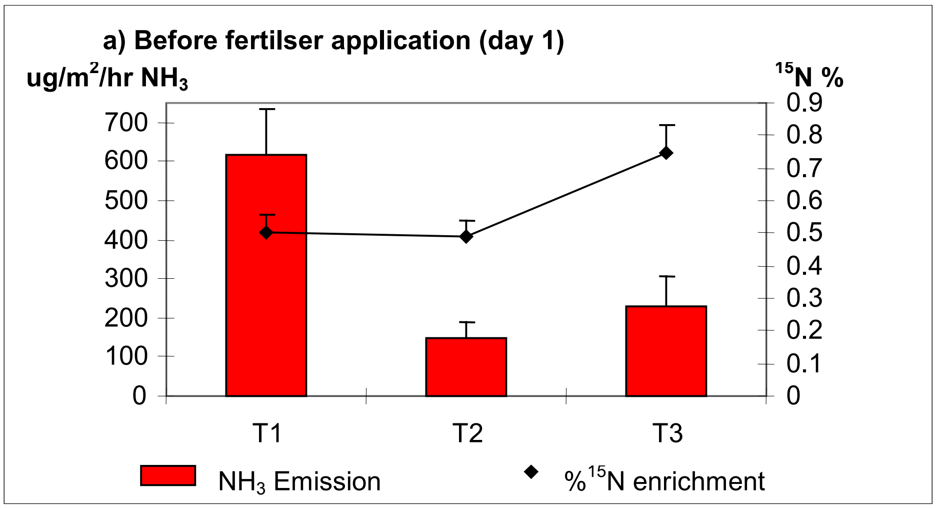
Table 17. Amounts of nitrate and potassium (mg) lost from three terraces of known area at Pakuwa in August 1998 in a 10 h period

	Bund 1	**Bund 2**	**Bund 3**
Nitrate	851.9	1219.4	1770.8
Potassium	1727.3	1525.6	1649.2
Area of terrace (m^2)	43.0	48.2	46.2

6.2.11 Gaseous losses of N from irrigated paddy

Prior to fertiliser application both ammonia and nitrous oxide emissions were low, less than 700 and 200 µg m^{-2} h^{-1}, respectively (Figures 15 and 16). It is difficult to scale up measured fluxes over time and space. However, for reference, an emission rate of 500 µg m^{-2} h^{-1} is equivalent to 0.12 kg ha^{-1} d^{-1}.

The rate of ammonia loss from the unfertilised plots was greater than for the plots where fertiliser or manure was added (Fig. 15). There are 2 possible explanations for this. First, poorer crop growth in the unfertilized plot causes a weaker sink for the ammonium produced by mineralization of soil organic matter leaving more ammonium in the soil. Since the ammonia concentration increases in proportion to the ammonium concentration, then ammonia losses will increase where there is more ammonium. Second, ammonia volatilization is determined by the pH of the flood water. This is controlled in part by the partial pressure of dissolved carbon dioxide which is determined by the balance between the rates of respiration and photosynthesis, particularly algae. There was less algal growth in the floodwater where no fertilizer had been applied.



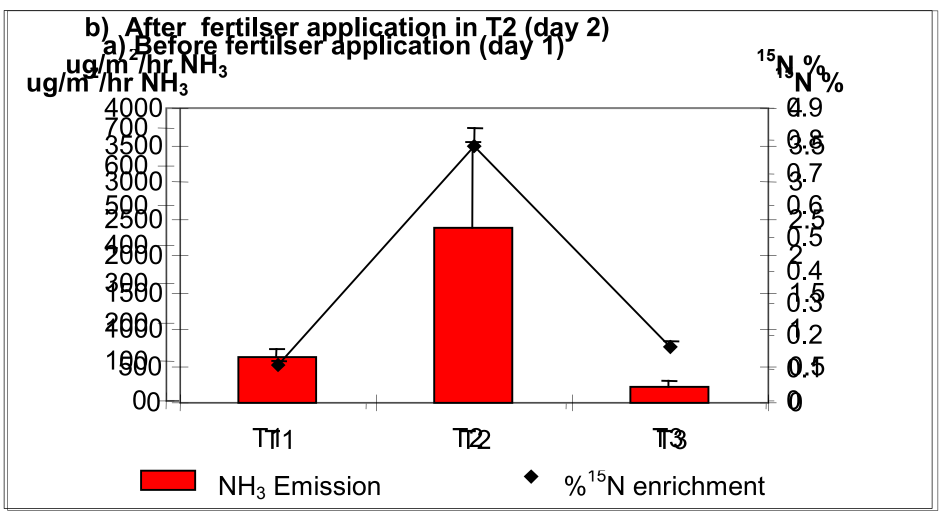
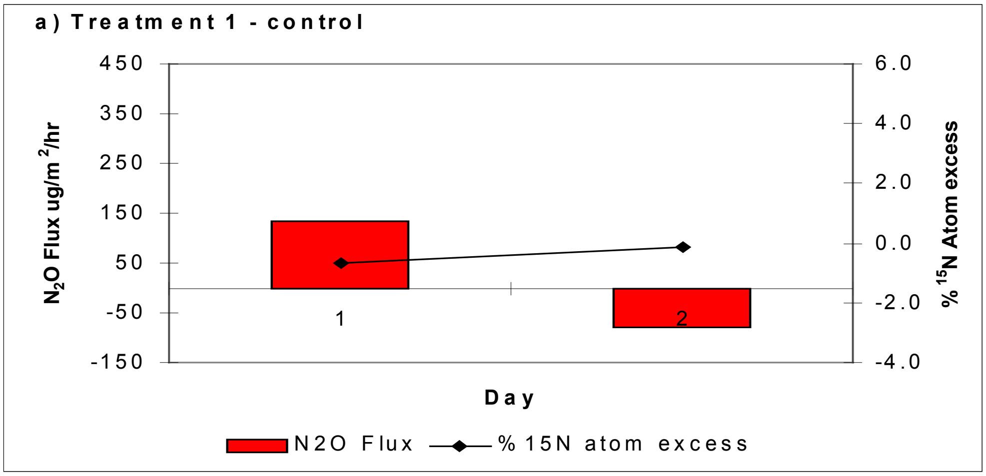


Figure 15. Ammonia emission (μg NH_3 m^{-2} h^{-1}) before (a) and after (b) application of ^{15}N-labelled urea at a rate of 25 kg N ha^{-1} to fertilized plots of rice on 3 August 1999 at Pakuwa. T1 was unfertilized and manure at a rate of 50 kg N ha^{-1} had been applied basally to T3.


a) Treatment 1 - control
450
350
250
150
50
-50
-150
6.0
4.0
2.0
0.0
-2.0
-4.0
N2O Flux ug/m2/hr
% 15N Atom excess
1
2
Day
N2O Flux
% 15N atom excess

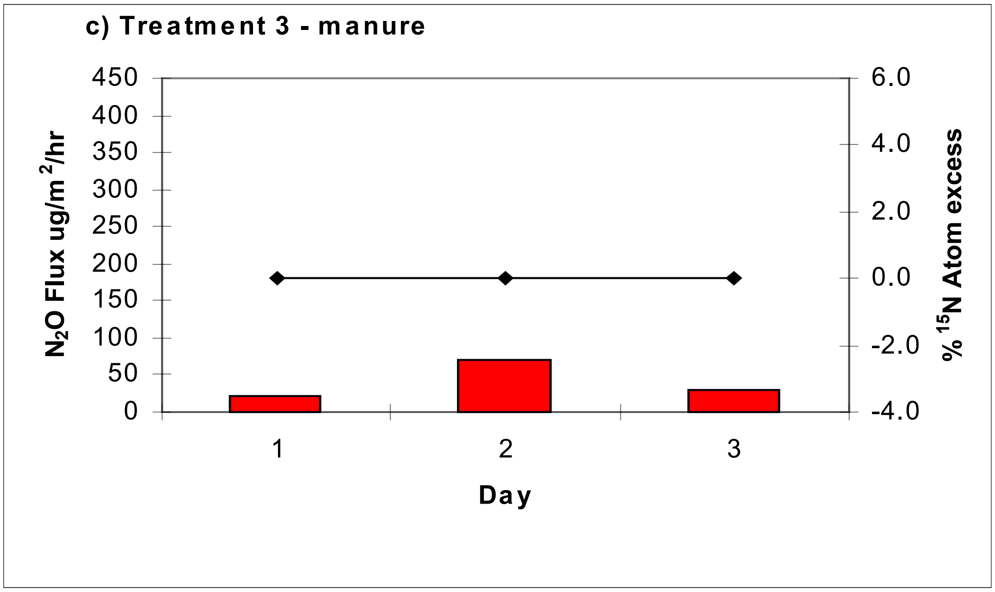
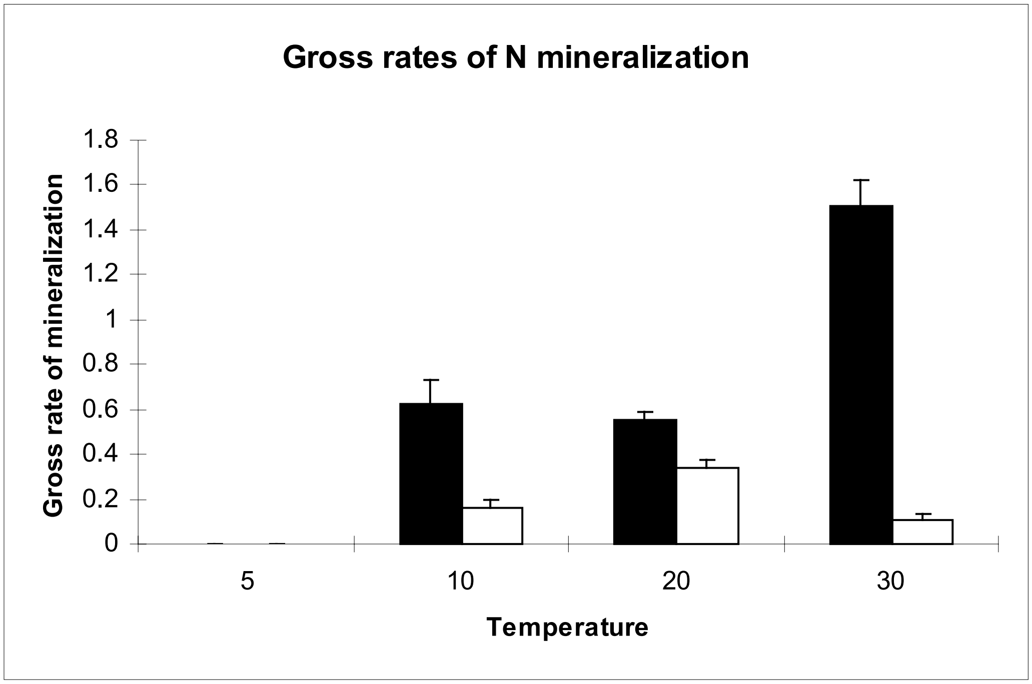


Figure 16. Effect of nutrient addition (1: no addition; 2: fertilizer; 3: manure) on the rate of nitrous oxide flux (ↄg N_2O m^{-2} h^{-1}) and ^{15}N enrichment of emitted nitrous oxide. ^{15}N-labelled urea was applied as a top-dressing at a rate of 25 kg N ha^{-1} to treatment 2 on day 2.

Immediately after fertilizer application the ammonia emission was increased from approximately 150 to 2000 µg m^{-2} h^{-1}.The increase in the enrichment confirmed that the source of lost nitrogen was the applied fertilizer. The rate of loss was less than 0.5 kg N ha^{-1} d^{-1}. Levels of ammonia emission dropped rapidly (< 24 h) to the background level prior to fertilizer application (data not shown).

Losses of nitrous oxide did not increase on the day of fertilizer application, but had increased 24 h after fertiliser application (Fig. 16). As with the ammonia emission the change in the ^{15}N enrichment of the nitrous oxide confirms that the fertilizer nitrogen was the source of nitrogen being emitted. The rate of nitrous oxide loss is relatively low; equivalent to *c.* 0.1 kg N ha^{-1} d^{-1}.

6.2.12 Gross Rates of Mineralization and Nitrification of N
Within a location soil moisture content had no effect on the gross rates of these processes. Averaging across moisture contents rates of both mineralization and nitrification were generally greater at Dordor Gaun than at Pakhribas (Fig. 17; Table 18). Responses to temperature were clearer in experiment 1 than in experiment 2, with an optimum temperature of 20°C for both processes at both sites.



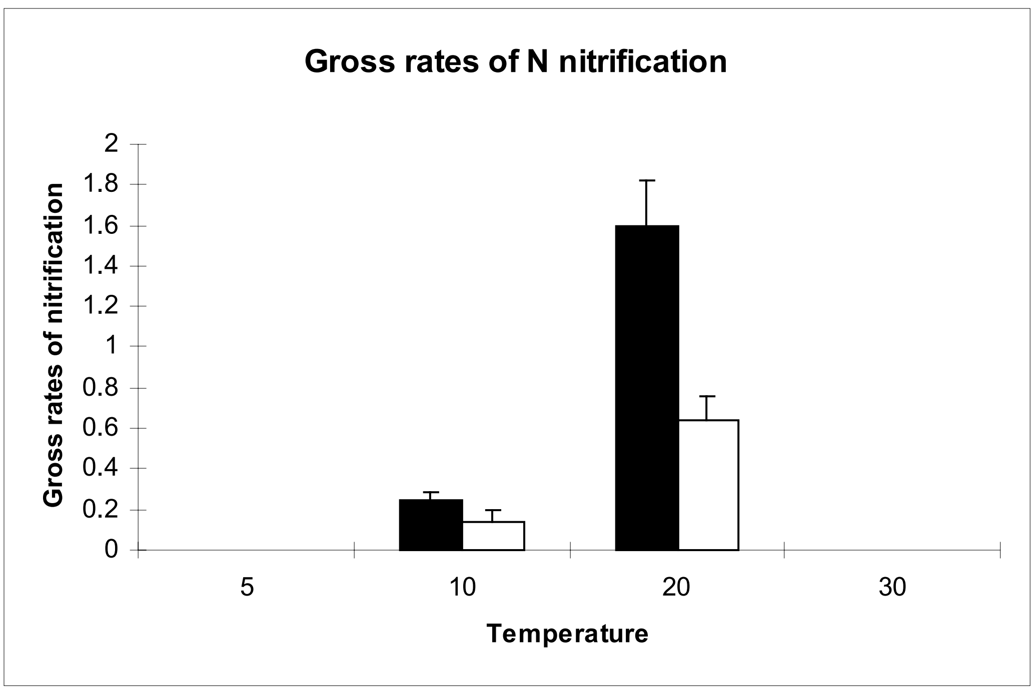


Figure 17. Average rates of mineralization and nitrification (mg N kg^{-1} d^{-1}) for soils from Dordor Gaun (solid bars) and Pakhribas (open bars) incubated at different temperatures and averaged over moisture content. Bars represent a standard error of the mean.

Table 18 . Average gross rates of mineralization and nitrification (mg N kg^{-1} d^{-1}) for soil from Dordor Gaun and Pakhribas incubated at 10 and 20 °C. Figures in parenthesis are standard errors of the means

Temperature (°C)	Dordor Gaun Mineralization	Nitrification	Pakhribas Mineralization	Nitrification
10	0.784 (0.024)	1.016 (0.005)	0.826 (0.021)	0.936 (0.009)
20	0.43 (0.056)	1.073 (0.032)	0.740 (0.007)	1.026 (0.033)

6.2.13 SUNDIAL modelling

Model simulations (Figures 1 and 2, Appendix 7) suggest that soil mineral N increases from early in the year to a maximum in June (> 40 kg N kg^{-1},depending upon treatment) before falling rapidly in early July and remaining at low levels (<10 kg N ha^{-1}). These patterns are perhaps predictable from the timing of applications of manure and fertilizer and from the increasing temperature and soil moisture contents which will stimulate rates of N mineralization.

SUNDIAL predicts the same overall patterns for crop N uptake for the different treatments as those measured in the experiment (Fig. 3, Appendix 7). However, it fails to accurately predict the relative balance between soil and fertilizer N sources within a crop (Figures 4 and 5, Appendix 7).

SUNDIAL outputs also allow the calculation of various indices of sustainability, efficiency and environmental impact (Scholefield and Smith, 1996)[1]. These are shown in table 9 (Appendix 7) for the data from Pakhribas. Clearly, any inputs create a more sustainable system than zero inputs. All treatments including the zero-input have an environmental impact, but the least damaging are the zero-input and the combination of manure and fertilizer applied at the low rate. Efficiencies are generally lower at the higher application rate.

6.3 OUTPUT 3: Local knowledge gained from surveys and experimental results synthesised and communicated to farmers and scientists.

6.3.1 FARMER FIELD DAYS

Farmers generally concluded that higher N applications gave better crops, *i.e.* treatments 2, 3 and 4 were scored higher than the others (e.g. Table 19). Applications of N fertilizer were often the basis for this favoured response, especially at Dordor Gaun/Dordor

[1] Scholefield, D and Smith, J.U. (1996). Nitrogen flows in ley-arable systems. Legumes in Sustainable Farming Systems. Craibstone.

Tar/Chambas. However, there is evidence from ARS-Pakhribas that farmers felt that applications of manure alone or in combination with fertilizer gave acceptable yields (Table 20). All farmers agreed that some amendment was better than none.

Table 19. Farmer's ranking of treatments (see above) and the reasons for these judgments for maize grown at Pakhribas and rice grown at Kholitar in 1997.

Crop	Treatments	Ranking	Reasons
Maize	2, 3, 5	Best	Medium plant height, Big cob size, No barren plants, Plants green at harvest.
	4, 6	Intermediate	Medium cob size, Few barren plants.
	1, 7	Worst	Small cob size, Short plant height, Several barren plants, Matured early.
Rice	2, 4	Best	Large and uniform plants (much straw) Big bold grains, Long panicles, Large number tillers per hill, Negligible sterility.
	3, 5, 6	Intermediate	Non-uniform plant height, Some sterility.
	1, 7	Worst	Short plants (little straw), Number of tillers per hill are not uniform, Low number of grains per panicle, Short panicle length, Sterility conspicuous, Early maturity.

Table 20. Rank order of treatments for wheat grown at Kholitar in April 1999 based on the modal preference for a particular treatment.

Treatment	Rank Position	Score from 22
1	7	15
2	4	13
3	1	19
4	2	18
5	5	14
6	3	19

7	6	14

6.3.2 SOCIOECONOMIC SURVEY

The survey recorded the response of 2081 households in 16 wards and provides a credible socio-economic perspective on the ways in which farmers from a variety of ethnic groups and wealth rankings manage soil fertility. Below are some highlights of the results, see appendix 6 for more detail.

- Based on the Household survey the average land holding per household was 1.06 ha divided approximately in a 2:1 ratio between rainfed bari/tar land and irrigated khet land.

- Analysis of the food self-sufficiency status of households in the area showed that in general <20 % of households have sufficient food for 12 months or more and >40 % have sufficient food for only 3 months. However, taking an average for a VDC disguises the large variability between wards, which is especially great for the 3 and 12 month categories. See Table 21 .

Table 21 . Status of food self-sufficiency in four selected wards of four surveyed VDC in 1999.

VDC	WARD NO.	FOOD SELF-SUFFICIENCY FOR				TOTAL HH
		3 months	**6 months**	**9 months**	**12 months**	
Pakuwa	1	65	16	10	12	103
	4	16	15	40	20	91
	5	30	15	10	4	59
	6	25	10	8	10	53
Bhanu	1	28	32	23	93	175
	4	40	40	20	100	200
	7	77	42	34	17	170
	8	300	100	50	50	500
Pakhribas	3	40	60	40	10	150
	6	10	20	15	7	52
	7	20	30	56	14	120
	8	37	10	25	12	84
Murti -dhunga	1	16	20	10	20	66
	2	36	35	10	10	91
	5	45	30	20	11	106
	9	25	17	10	9	61

- Most farmers believed that their land was less fertile now than 10 years ago, and that the greatest changes were found on bari land.

- A majority of farmers apply chemical fertilizers (frequently urea or DAP) to their main crops (wheat, rice and maize) but without necessarily understanding the differences between fertilizer type and importance of appropriate application rates.

- Many farmers felt that the continuous application of chemical fertilizers without addition of FYM was causing the soil to deteriorate, and that crop productivity was consequently declining. A related phenomenon was the increase in draught requirement, or number of ploughings, during land cultivation, *i.e.* the continuous use of chemical fertilizer appeared to be hardening the soil.

- About one-third of respondents had increased their application rate of fertilizer, however 22 % of respondents had reduced their use of manure. The reasons given for the decline in the use of FYM were lack of labour, government control of community forests, and less available products within the forest.

- More FYM is applied to bari land than to khet land, particularly to potato and maize, and then to wheat, mustard and blackgram.

- While farmers prefer FYM from small animals, larger animals produce more and so the manure composition is dominated by dung from large ruminants. However, in most VDCs the number of animals has declined over the last 10 years. 72 % of respondents stall-fed their animals because there was limited available grazing land and to ensure closer supervision of animal health.

- Both men and women are involved in making FYM. Women collect green leaves, fodder and grasses for feed, clear the animal sheds of manure and litter and place these into the pit. They also transport the manure to the field where they spread it. Men dig the storage pits, turn the manure in the pit, and assist with the spreading in the field. It was estimated that farmers in the mid-hills of Nepal spend 81 days per year preparing and managing manure.

- Most farmers prefer to use both fertilizer and FYM, but sole applications of FYM are preferred to sole applications of fertilizer.

- Multiple cropping is now the dominant practice compared with monocropping in the past. The dominant rotations are maize-millet on the bari land of Pakuwa, Pakhribas and Murtidhinga VDCs, and upland rice-blackgram in Bhanu VDC. Rice-wheat is the dominant cropping pattern on the khet land in all VDCs.

- Based on the results of the household survey food and clothes were the highest priority for household expenditure followed by schooling and the purchase of daily necessities such as salt, kerosene and edible oils. Chemical fertilizers and FYM were the lowest priority for expenditure.

6.3.3 ECONOMIC ANALYSIS OF TRIAL RESULTS

Margins were generally negative when manure was applied either alone or in combination with fertilizer, but positive with applications of fertilizer. For most crops, labour costs exceeded the market value of the yields from the zero-input treatment. Clearly the economic benefit of different nutrient management practices is crucially dependent upon the value attached to manure and to labour. More discussion of this analysis is given in appendix 4.

7. CONTRIBUTION OF OUTPUTS

The original developmental goal sought to improve the sustainability of commodity production systems by enhanced soil fertility. This project provides a sound technical basis for understanding the current soil fertility limitations to crop production in a wide range of farming systems. This technical information has been made available to NARS scientists and extensionists through technical reports, journal articles and a technical workshop held at the Dhulikhel Mountain Resort, and to farmers through field days held at the experimental sites. Based on this information a number of preliminary recommendations were identified at the workshop, for example:

- use a balanced combination of organic manures and inorganic fertilizers;
- use split applications of inorganic fertilizers to increase nutrient use efficiency; and
- promote the more extensive use of higher quality FYM.

It was envisaged originally that these preliminary recommendations would be refined into recommendations for integrated nutrient management suitable for resource poor farmers in a second phase of the project funded by DFID through the Hillsides programme.

The investigations of the project have not however been exclusively biophysical. It has also thoroughly characterized the socio-economic context in which farmers make decisions relating to the management of soil fertility in the hillside environment. This activity has complemented the biophysical investigations, and the utilization of the outputs from this combination of activities now provides an unparalleled opportunity for developing technically sound recommendations relevant to the needs of specific identifiable household groupings, for example:

- those without access to fertilizer;
- those with few livestock;
- those growing particular crop combinations;
- those without a male-head of household; and
- those with different levels of resource.

This careful targeting of recommendations to the needs and opportunities of identifiable end-users would ensure greater adoption of the proposed recommendations, and enhance likely impact. This opportunity has been missed with the non-renewal of funding support.

8. DISSEMINATION

8.1 JOURNALS

Sherchan, D.P., Pilbeam, C.J. and Gregory, P.J. (1999). Response of wheat-rice and maize/millet systems to fertilizer and manure applications in the mid-hills of Nepal. *Experimental Agriculture* 35: 1-13.

Pilbeam, C.J., Tripathi, B.P., Munankarmy, R.C. and Gregory, P.J. (1999). Productivity and economic benefits of integrated nutrient management in three major cropping systems in the mid-hills of Nepal. *Mountain Research and Development* 19(4): 333-344.

Pilbeam, C.J., Tripathi, B.P., Sherchan, D.P., Gregory, P.J. and Gaunt, J. (0000). Nitrogen balances for households in the mid-hills of Nepal. *Agriculture, Ecosystems and Environment* In Press

8.2 OTHER PUBLICATIONS

Pilbeam, C.J., Gregory, P.J., Tripathi, B.P., Acharya, G.P., Sherchan, D.P., Gurung, G.B. and Gaunt, J. (1997). Integrated nutrient management to sustain crop production in the mid-hills of Nepal. pp. 247. In: Fertilization for sustainable plant production and soil fertility. Eleventh World Fertilizer Congress, Ghent, Belgium. September 1997.

Pilbeam, C.J., Gregory, P.J., Tripathi, B.P., Acharya, G.P., Sherchan, D.P., Gurung, G.B. and Gaunt, J. (1997). Integrated nutrient management to sustain crop production in the mid-hills of Nepal. pp. 251. In: Integrated Nutrient Management on Farmers' Fields: Approaches that work. (eds. P.J. Gregory, C.J. Pilbeam and S.H. Walker). The Department of Soil Science, The University of Reading, Occasional Publication Number 1. The University of Reading, Reading:UK

Pilbeam, C.J., Gregory, P.J., Tripathi, B.P., Acharya, G.P., Sherchan, D.P., Gurung, G.B. and Gaunt, J. (1998). Integrated nutrient management to sustain crop production in the mid-hills of Nepal. In: Sixteenth World Congress of Soil Science. Montpellier, France. August 1998. CD-Rom.

Pilbeam, C.J., Gregory, P.J., Tripathi, B.P., Acharya, G.P., Sherchan, D.P., Gurung, G.B. and Gaunt, J. (1998). Integrated nutrient management to sustain crop production in the mid-hills of Nepal. In: Present functioning of the World Soil Systems in relation to the various types of land use by human societies. (ed. C.J. Pilbeam). Department of Soil Science, The University of Reading, Occasional Publication Number 3. The University of Reading, Reading: UK.

Pilbeam, C.J., Gregory, P.J., Munankarmy, R.C. and Tripathi, B.P. (1999). N transformations following the application of urea to low-input maize cropping systems in the mid-hills of Nepal. pp.I. 19. In: Tenth Nitrogen Workshop, The Royal Veterinary and Agricultural University, Copenhagen, Denmark, August 1999.

Tripathi, B.P., Acharya, G.P., Gregory, P.J. and Pilbeam, C.J. (1998). Effect of organic and inorganic fertilizers in different cropping systems in the western hills of Nepal. pp. 385-386. In: Agronomy, Environment and Food Security for 21st Century. First International Agronomy Congress, New Delhi, India, November 1998.

Sherchan, D.P., Tripathi, B.P., Pilbeam, C.J., Acharya, G.P., Gregory, P.J. and Jha, A.K. (1998). Integrated nutrient management for sustainable crop production in the mid-hills of Nepal. pp. 63-64. In: Agronomy, Environment and Food Security for 21st Century. First International Agronomy Congress, New Delhi, India, November 1998.

Pilbeam, C.J., Gregory, P.J., Tripathi, B.P. and Munankarmy, R.C. (1999). Nitrogen fluxes through sustainable farming systems in the mid-hills of Nepal. In: Sustainable Management of Soil Organic Matter. British Soil Science Society Meeting, Edinburgh, September 1999. CABI, Wallingford, UK. (In press).

8.3 WORKING PAPERS

(available from ARS-Lumle, P.O. Box 1, Pokhara, Kaski, Nepal)

Tripathi, B.P., Acharya, G.P., Gregory, P.J. and Pilbeam, C.J. (1998). First cycle of long-term soil fertility experiments on rice-wheat, upland rice-blackgram and maize-finger millet systems in the western hills. LARC Seminar Paper 98/18. Kaski, Nepal: Lumle Agricultural Research Centre.

Tripathi, B.P., Acharya, G.P., Gregory, P.J. and Pilbeam, C.J. (1998). Long-term soil fertility trial on upland rice-blackgram system in Tar area of western region (1997/98). LARC Working Paper 98/28. Kaski, Nepal: Lumle Agricultural Research Centre.

Tripathi, B.P., Acharya, G.P., Gregory, P.J. and Pilbeam, C.J. (1998). Long-term soil fertility trial on rice-wheat system in the river basin/hill bottom under low land (khet) condition of western development region (1997/98). LARC Working Paper 98/31. Kaski, Nepal: Lumle Agricultural Research Centre.

Tripathi, B.P., Acharya, G.P., Gregory, P.J. and Pilbeam, C.J. (1998). Long-term soil fertility trial on maize-finger millet system in the western hills of Nepal 1997/98. LARC Working Paper 98/35. Kaski, Nepal: Lumle Agricultural Research Centre.

Pilbeam, C.J., Tripathi, B.P. and Acharya, G.P. (1998) Estimation of nitrogen fixation by blackgram using ^{15}N techniques. Lumle Working Paper 98/41. Kaski, Nepal: Agricultural Research Station, Lumle.

Pilbeam, C.J., Tripathi, B.P. and Acharya, G.P. (1998). Recovery of ^{15}N-labelled urea fertilizer immediately after application to bari-land. Lumle Working Paper 98/42. Kaski, Nepal: Agricultural Research Station, Lumle.

8.4 UNPUBLISHED PAPERS

Pilbeam, C.J., Sherchan, D.P. and Gregory, P.J. (1998). Quantifying the yield benefit of integrated nutrient management from long-term wheat-rice and maize/millet rotations in the hills of Nepal. A paper presented at a workshop, “Long-term fertility experiments on various cropping patterns” held at NARC, Kathmandu, 11-13 August 1998.

Pilbeam, C.J., Tripathi, B.P., Munankarmy, R.C. and Gregory, P.J. (1999). Productivity and economic benefits of integrated nutrient management to three major cropping systems in the mid-hills of Nepal. A paper presented at a conference, “Poverty, Rural Livelihoods and Land Husbandry in Hillsides Environments” held at Cranfield University, Silsoe, 6-8 January 1999.

8.5 REPORTS

(Available from Dept. of Soil Science, The University of Reading, Whiteknights, Reading, RG6 6DW, UK)

Ellis-Jones, J. and Maskey, R.B. (1998). Mid term project review. R6757 Soil Fertility management for sustainable hillside farming systems in Nepal. DFID NRSP/NARC.

Mathema, S.B., Shakya, P.B. and Pilbeam, C.J. (1999). Socio-economic research on management of soil fertility in mid hills of Nepal. Main Report (Volume 1). Department of Soil Science, The University of Reading, Reading, UK. pp170.

Mathema, S.B., Shakya, P.B. and Pilbeam, C.J. (1999). Socio-economic research on management of soil fertility in mid hills of Nepal. Annexes (Volume 2). Department of Soil Science, The University of Reading, Reading, UK.

8.6 TELEVISION

A soil fertility video prepared by ARS-Lumle was presented on Nepali TV on 27 May 1998. This documentary made reference to this project, and showed interviews with farmers who had attended a field day at our Chambas field site.

APPENDIX 1.

Project Inventory

APPENDIX 2.

Manuscript, “Nitrogen balances for households in the mid-hills of Nepal”

C.J. Pilbeam, B.P. Tripathi, D.P. Sherchan, P.J. Gregory and J. Gaunt.

Journal: Agriculture, Ecosystems and Environment (In Press).

APPENDIX 3.

Report, "Nutrient flow budgets for Nepali agricultural systems"

S. White, S. Fortune, C.J. Pilbeam and J. Gaunt.

APPENDIX 4.

Manuscript, “Productivity and economic benefits of integrated nutrient management in three major cropping systems in the mid-hills of Nepal”

C.J. Pilbeam, B.P. Tripathi, R.C. Munankarmy and P.J. Gregory.

Journal: Mountain Research and Development (1999) 19(4): 333-344.

APPENDIX 5.

Manuscript, "Response of wheat-rice and maize/millet systems to fertilizer and manure applications in the mid-hills of Nepal"

D.P. Sherchan, C.J. Pilbeam and P.J. Gregory.

Journal: Experimental Agriculture (1999) 35:1-13.

APPENDIX 6.

Report, “Socio-Economic research on management of soil fertility in the mid-hills of Nepal: Main Report (Vol. 1)”.

S.B. Mathema, P.B. Shakya and C.J. Pilbeam.

APPENDIX 7.

Report, “Modelling nitrogen cycling in the arable systems of Nepal using SUNDIAL”.

P. Falloon, C.J. Pilbeam and J. Smith.

Table 4. Dates of sowing, top-dressing and harvesting of different crops at each location during the project.

Location	Crops	First-Cropping Cycle			Second-Cropping Cycle			Third-Cropping Cycle		
		Sow/Plant	Top-Dress	Harvest	Sow/Plant	Top-Dress	Harvest	Sow/Plant	Top-Dress	Harvest
Dordor	Maize	21-22/4/97	3/6/97	19/8/97	26/4/98	8/6/98	18-19/8/98	15/5/99	22/6/99	28-29/8/99
Gaun	Millet	21-23/8/97	-	6-7/12/97	20-21/8/98	-	25/11/98	30-31/8/99		1/12/99
Dordor Tar	Upland Rice	24,30/4/97	10/6/97	4-5/9/97	18/4/98	7/6/98	31/8-1/9/98	18-19/5/99	21/6/99	6-7/9/99
	Blackgram	6/9/97	-	3-4/12/97	2/9/98	-	25/11/98	9/9/99	-	29/11/99
Pakuwa	Rice	9-10/7/97	16/8/97	25-27/11/97	3/7/98	18/8/98	12/11/98	8/7/99	3/8/99	17/11/99
	Wheat	18-19/12/97	16/1/98	29-30/4/98	5/12/98	3/1/98	11/4/99	29/11/99	-	-
Chambas	Rice	17-19/7/97	18/8/97	30/11-2/12/97	10/7/98	14/8/98	17/11/98	13/7/99	14/8/99	15-16/11/99
	Wheat	7-8/12/97	22/1/98	24-25/4/98	1-2/12/98	31/12/98	12/4/99	3/12/99	-	-
Kholitar	Rice	26/6/97	28/8/97	26/11/97	7/7/98	18/8/98	12/11/98	25/6/99	22/7/99	18/11/99
	Wheat	24/12/97	10/3/98	17/5/98	23/11/98	5/1/99	12/4/99	29/11/99		
Pakhribas	Maize	15/4/97	3/7/97	30/9/97	16/4/98	16/6/98	6-7/9/98	28/4/97	22/6/99	26/9/99
	Millet	14/7/97	-	3/12/97	18/8/98	-	26/11/98	16/8/99	-	
Sindhuwa	Potato	-	-	-	22/1/98	-	15/7/98	13/1/99	-	7/7/99
	Maize	-	-	-	3/3/98	14/6/98	22/9/98	1/4/99	8/7/99	1/10/99