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The development of interventions to minimise soil and nutrients losses in the Bari land of the middle hills of western development region of Nepal

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THE DEVELOPMENT OF INTERVENTIONS TO MINIMISE SOIL AND NUTRIENTS LOSSES IN THE *BARI* LAND OF THE MIDDLE HILLS OF WESTERN DEVELOPMENT REGION OF NEPAL

A thesis submitted in candidature for the degree of Philosophiae Doctor

by

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DEDICATION

THIS THESIS IS DEDICATED TO MY LATE PARENTS

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ABSTRACTS

This thesis presents the results of field experiments on soil, water and nutrient conservation and measurement. The main objective of this research was to identify suitable technology to minimise soil loss and improve soil fertility in farmers' fields involving local knowledge and farmers' participation in the research. The experiments were conducted at different agro-ecological sites in the middle hills of Nepal.

Nayatola was selected, a representative site for sloping land cultivation system and low to medium rainfall in the middle hills. The altitude of the area in which experiments were conducted is ranged from 1100 to 1400 m asl and annual rainfall is 800-1400 mm. Farmers have adopted a maize-based cropping system with farmyard manure application and a small area of ginger with mulching practice as a cash crop in sloping *bari* lands. Landruk was selected, a representative site for bench terracing system and high rainfall. Experiments were conducted at the altitude ranging from 1400-1600 m asl where maize/millet and maize/wheat or barley are main cropping systems receiving 3000-3600 mm annual rainfall. Bandipur was another site selected, a representative for citrus growing pocket areas. This site receives 1000-2000 mm annual rainfall and having bench terracing system with maize and upland rice based cropping systems and citrus orchards. The altitude of experimental site is ranged from 900 to 1100 m asl.

Results indicate that a low proportion of rainwater flows into runoff compared with infiltration in the soil in all sites. However, some erosive rainfall events occurred during the early season resulting in heavy soil loss.

Ginger strip with mulch alternating with maize strips across the slope reduced soil loss from 144 - 1756 kg/ha/yr to 58 - 281 kg/ha/yr in the maize-based cropping system on the sloping bari lands at Nayatola. A legume crop such as soybean in strips alternating with maize strips also reduces soil loss from 867-1756 kg/ha to 555-865 kg/ha and improved soil fertility in the bari lands.

Run-on diversion reduced soil loss from 886 - 7256 kg/ha/yr to 478 - 4653 kg/ha/yr from bench terraces under high rainfall conditions at Landruk. Grass planted in terrace risers can also reduce soil loss from cultivated terraces once roots have been established. *Setaria*

aneps is a suitable species for cultivation in terrace risers in Landruk and Bandipur areas. However, it requires 2-3 years for establishment in risers and repeated planting in the early years. Native grass species dominated for the first few years. After three years *Setaria* covered whole risers, produced more grass and minimised soil loss compared to risers dominated by native grasses. The planting operation accelerated soil erosion during the first two years.

The narrow-terraced maize-based system is more sensitive to soil erosion compared to the wide-terraced maize-based system. The narrow-terraced maize-based system lost higher amount of soil (812 - 2804 kg/ha/yr) than the wide-terraced maize-based system (222 - 745 kg/ha/yr) in Bandipur. An intercrop of legume was found to reduce soil erosion in areas of citrus cultivation.

Organic carbon is the most important element lost in sediment. 8.5 - 56.9 kg/ha/yr organic carbon was lost in the control plot at Nayatola, 69.6 - 182.1 kg/ha/yr was lost in the control plot at Landruk and a maximum of 14.5 kg/ha/yr organic carbon was lost at Bandipur. These losses were reduced to 1.1 - 15.2 kg/ha/yr with ginger and maize strip cropping at Nayatola and 35.2 - 83.3 kg/ha/yr with run-on diversion at Landruk. Young citrus orchards with an intercrop lost the least organic carbon (3.0 -7.6 kg/ha/yr) at Bandipur.

Total nitrogen lost in sediment ranged from 0.1 - 18.1 kg/ha/yr. Nitrogen loss in sediment was higher at Landruk compared with Nayatola and Bandipur. Available P content was higher in sediments (30-162 mg/kg) than in soils (12-52 mg/kg) at all sites. Sediment loss therefore has an effect on the available P in the soil.

With low soil loss there was less loss of carbon, P and N in the sediment. However, there was a huge amount of NO_3-N and K lost in leachate. Strip cropping of ginger and maize and diversion of run-on encourage nutrient loss via leachate. Diversion of run-on minimised soil loss and enhanced water infiltration in the soil. Dissolved N, P and K were not lost in significant quantities in runoff.

Therefore, strip cropping of maize and ginger with mulch and maize and legume is beneficial to minimise soil and nutrient losses from sloping *bari* lands in the middle hills. Run-on diversion followed by fast growing grass planting in terrace risers is beneficial to minimise soil and nutrient loss in bench terraced high rainfall areas. Intercropping of legumes in citrus orchard is found the best practice to reduce soil and nutrient losses in Bandipur, a pocket area of citrus cultivation.

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ACRONYMS AND ABBREVIATIONS

ANOVA	Analysis of variance
ARS	Agriculture Research Station
Av.	Available
CEC	Cation Exchange Capacity
DFID	Department of International Development
E. monsoon	Early monsoon
EI	Erosivity index
Exch.	Exchangeable
Fig.	Figure
FYM	Farmyard manure
g	gram
ha	hectare
K	Potassium
KE	Kinetic energy
kg	kilogram
L. monsoon	Late monsoon
m	metre/million
M. monsoon	Mid monsoon
meq	milli equivalent
mg	milligram
MJ	Mega Joules
mm	millimetre
N	Nitrogen
NaOH	Sodium hydroxide
NO_3-N	Nitrate-nitrogen
NT/MB	Narrow-terraced maize-based

OC	Organic Carbon
OCO	Old citrus orchard
P	Phosphorus
PC	Package
QMWC	Queen Mary and Westfield College
REP	Replication
t	tonne
TN	Total nitrogen
U.K.	United Kingdom
U.S.A.	United States of Amarica
W.monsoon	Whole monsoon
WT/MB	Wide-terraces maize-based
YCO	Young citrus orchard
Yr	Year

CHAPTER 1

GENERAL INTRODUCTION

1.1 INTRODUCTION

The soil is a natural resource without which crop production would not be possible. Food production for humans and animals is dependent upon soil fertility. The skilled producer protects and maintains natural resources and manipulates them to ensure a sustainable increase in production. A number of factors cause deterioration of soil fertility thereby adversely affecting crop production. The loss of fertile soil from cultivated lands is becoming a major problem in crop production systems across the world, especially in Nepal where its economy is largely dependent upon agriculture. The nature of the soil, the amount, pattern and distribution of rainfall, existing cropping practices and land cultivation systems, availability of resources and awareness of the farming community are all factors affecting soil fertility and land degradation in the hills of Nepal. The total area of cultivated land in mountains and hills of Nepal is 130200 and 756000 hectares respectively (Anonymous, 1978). Farmers living in the middle hills are dependent on the rainfed agriculture of their *bari* lands. The *bari* lands comprise non-irrigated and non-bunded terraces. Soil fertility and its sustainable management for crop production is becoming a priority issue in the middle hills. The maintenance of soil fertility in Nepal's existing farming system would provide a great contribution to the economy and well-being of a large proportion of its farmers.

This is a systematic study of decreasing soil fertility and proposes important solutions. Measures to minimise loss of fertile soil through runoff and loss of nutrients through leaching could contribute to the maintenance of soil fertility in *bari* lands in the hills of Nepal. Land use, type of farming system, soils and climate have played an important rôle in the degradation of soil fertility, especially in the *bari* lands of the middle hills. Their study assists resource conservation planning.

The Western Development Region of Nepal consists of the middle hills which are representative of the land use system, cropping systems and climatic variation of the country. *Bari* lands are approximately 192940 hectares (29% of the country) of the region (Anonymous, 1997 and Joshi, 1998).

1.2 LAND USE SYSTEM

The middle hills make up 30% of the land area of Nepal. Most of the cultivated land extends to an elevation of 1500 m above sea level and has a slope angle of 30° (Carson *et al.*, 1986). Hill farming extends from river basins to high hills covering almost all aspects. A bench terracing system exists in the eastern hills where rainfall is comparatively high. An outward sloping terrace system exists in the western hills. Bench terraces have less than a 5° slope whereas sloping fields have a slope up to 50° under cultivation. Cultivated land that is bench-terraced or has an outward slope of 5 to 50° faces increasing problems of soil fertility loss. The middle hills of the country have no irrigation facility despite large perennial rivers crossing the middle mountain from the high mountain to the Sivalik region. Small side streams do not flow after August-September and irrigation is impossible because of the elevation difference between the level of rivers and adjoining cultivated fields (Carson *et al.*, 1986). Agriculture in the middle hills is totally rainfed; it depends on monsoon rain in the summer and residual moisture and occasional rain showers during the winter. The rainfed agricultural land in the hills is called *bari* land. The *bari* land occupies 50% of the middle hills land area. The population level of this area is high although there is a tendency for migration from these areas to the low hills/valleys and cities.

1.3 CROPS AND CROPPING SYSTEMS

In the *bari* land farmers grow upland rice (*Oriza sativa*), maize (*Zea mays*), finger millet (*Eleusin coracama*) and some legumes in summer. Wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), naked barley (*Hordeum vulgare var. nudum*), pea (*Pisum sativum*) and mustard (*Brassica spp.*) are grown in winter. There are 112 cropping patterns prevailing in the hills and a maize/millet-fallow system covers 35% of *bari* land (Acharya, 1999). In the summer some farmers grow ginger (*Zingiber officinale* Roscoe) as a cash crop in pockets within the maize. This involves mulching (covering the land surface with plant material). Millet and legumes such as soybean (*Glycine max* Merr), field bean (*Phaseolus vulgaris*) and cowpea (*Vigna unguiculata*) are inter-cropped with maize. There are pocket areas of commercial citrus farming where inter-crops are grown in the citrus orchard until the citrus plants are fully grown. The winter crops are sequential and mixed. Two or more crops are grown after maize in the same field. In addition, the high hill farmers grow potatoes (*Solanum tuberosum*) as an inter-crop in maize followed by barley, naked barley or wheat in the sequence. At higher altitude (above 1200 m) the crops take longer to mature so farmers follow a crop rotation system. In the first year maize/millet is grown. Maize is planted in April and millet in May-June. The maize is harvested in September and the millet in late November. The field remains fallow from December to March. In the second year maize is mixed with legumes in March and both are harvested in September. Wheat, barley or naked barley is then sown in September either alone or mixed with mustard, pea or both mustard and pea to be harvested in March-April. Crop yields are satisfactory during the summer. Better soil cover in the crop fields improves water infiltration and increases crop yield by reducing erosion and stabilising soil mineral and organic balances (Barry *et al.*, 1995). The conservation tillage practice must be sustainable within the yearly crop rotation (Krzic *et al.*, 2001).

There is an increasing trend in the development of community forest and protection of natural forest in Nepal. User groups are involved in the management of forests and are focussed on forest regeneration in marginal land (Chhetri and Jackson, 1995). Catchment areas with high forest cover (50%) have a lower runoff (18% of the annual rainfall) and lower sediment loss (4.69 t/ha) compared with catchment areas having lower forest cover where runoff is 41.3% and sediment loss 9.13 t/ha (Joshi *et al.*, 1998).

1.4 LAND CULTIVATION SYSTEM

Farmers cultivate their land using wooden ploughs driven by bullocks. Whilst the crop is standing in the field spades are used for earthing up the maize, inter-cropping millet and weeding. Cultivation of land to control weeds increases erosion and conventional tillage causes unacceptable levels of soil loss (Giraldeze *et al.*, 1989). Maize is planted by dropping seeds a foot apart into furrows. This is carried out in March or June depending on soil moisture availability/rainfall, expected sequential crops, altitude etc. Manure and fertilisers are applied and mixed with the soil by ploughing. Fields are ploughed a number of times before crops are planted. Chisci *et al.* (1989) observed that traditional deep ploughing of dry soil during the summer was effective in restoring soil macroporosity but increased the risk of soil erosion. In ginger planting farmers follow a mulching practice.

This avoids the use of intercultural operations to control weeds and also reduces soil erosion. Smolikowski *et al.* (1998) observed sediment loads and erosion coefficients to be 15.9 and 1.5 times higher respectively on conventional tillage plots compared with the mulched plot (50% slope) in a semiarid region of Santiago Island.

1.5 SOIL TYPES AND SOIL FERTILITY

The soil-forming parent materials in the middle hills of Nepal are predominantly phyllites, quartzite, mica schist with granite and limestone (Carson *et al.*, 1986). The majority of gently sloping cultivated lands have phyllitic and quartizitic colluvial parent materials and erosional processes are extreme. Tripathi (1997) reported the presence of inceptisols and entisols in the high and middle hills. The agricultural soils therefore have a strong colluvial component originating from the entisols and are acidic due to leaching of the bases from the surface soil in areas of high rainfall. Farmers have their own criteria for soil classification and differentiate types on the basis of soil colour, texture and depth, in combination with slope (providing information on drainage), soil moisture retention capacity and organic matter content (Shah, 1995).

The soil fertility management practice most prevalent in the northern belt of the country (especially in the higher hills) is *in situ* manuring in which farmers keep animals on the terraces for direct manuring of the fields. This practice eliminates manure transportation costs. In other hilly areas farmers house their animals. Dung and old bedding materials are collected and stored in pits or heaps for use in the field. Farmers use inorganic fertilisers when they have the resources. The inorganic fertilisers are used to supplement farmyard manure (Pandey *et al.*, 1995). Their use is concentrated in the low hills and river basins. Middle hill farmers rarely use inorganic fertilisers in their *bari* land. Farmers believe that their fields become fertile with the addition of more manure and fertilisers. They believe that fields receiving less manure and fertiliser will suffer a decrease in soil fertility and crop productivity. Manuring of the fields closest to the farmers' households and irrigation facilities is a priority as here they can easily look after their crops, increasing the cropping intensity of economically important crops.

The availability of nutrient resources (especially farmyard manure) is decreasing and consequently application in the field is in decline. Farmers are only applying farmyard manure (FYM) to small land areas in order to achieve a satisfactory yield and no residue remains in the soil after harvest of the summer season crops. The reasons for decreasing soil fertility include decrease in the quantity of manure production, use of high yielding crop varieties and erosion. Marginal and bare land is prone to soil erosion. This leads to the loss of nutrients, organic matter and fertile soils through runoff during the rainy season. The loss of soil nutrients from farm fields is mainly due to runoff of the top layer of fertile soil during the rainy season. Soil fertility in the hills is decreasing. Nutrient uptake and loss is high when compared with nutrient recycling in the soil. FYM is the main plant nutrient resource and is applied to the fields before the crops are planted. The increasing trend for community forest has limited the use of forest resources in livestock farming, ultimately reducing the number of farm animals and hence the production of FYM. The reduction in the number of farm animals due to scarcity of fodder, bedding materials and leaf litter ultimately reduces the amount of farmyard manure and compost production. The decrease in the production of farmyard manure has forced farmers to concentrate on small areas of land (leaving more land marginal) and to use high yielding crop varieties leading to extraction of more nutrients from the soil.

1.6 CLIMATIC CONDITIONS

Rainfall in the hills of Nepal mainly occurs in the summer. It ranges from 800 to 2000 mm per year. The eastern part of the country is the high rainfall zone and the western part is the low rainfall zone. In contrast to the short summer period the rest of the year hardly receives 100 mm of rainfall. The exception to this is found in the hills of the Kaski district around Pokhara where rainfall is extremely high and exceeds 6000 mm during summer each year (ARS, Lumle's record). With high intensity rainfall in the summer there is loss of soil and nutrients. Rainfall pattern is one of the major factors affecting soil erosion. Rainfall detatches soil and produces runoff. The amount of soil loss depends on the energy of the rain and the soil's erodibility. The erosion is a function of the erosivity of rainfall, measured by its amount and intensity (Hudson, 1995). High rainfall causes erosion even on bench terraces having a low slope angle. The rainfall of high intensity for short period can also cause serious erosion.

1.7 SOIL FERTILITY MAINTENANCE IN THE MIDDLE HILLS OF NEPAL

Increasing populations have a greater demand for food production. Increase in food production is only possible either through increasing crop yield per unit area or increasing the area of land under cultivation. Over a 34 year period there was a 10% increase in agricultural land from forest land in Nepal (Shrestha and Brown, 1995). The change from forest land to agricultural land has increased surface soil loss. In Jamaica runoff levels have increased by 360, 460 and 740% from agroforestry, bare land and agricultural land respectively compared with forest land (McDonald *et al.*, 2002). A change of primary forest land to arable cropping causes a decrease in organic matter in the topsoil (Watable *et al.*, 2001). Farmers widely support the view that the soil fertility is declining in the hills irrespective of land type (Vaidya *et al.*, 1995). The application of nutrient resources to farm fields is dependent upon their availability and their cost. The plant nutrient resource in the hills is farmyard manure, the production of which is dependent on forest products and farm animals. Again, it is necessary to maintain soil health in farm fields to ensure higher yields. These constraints limit the efficient use of plant nutrients and their protection from loss as an alternative soil fertility management tool.

Nutrients can be conserved using appropriate technologies. The indigenous approaches include the adoption of terracing, runoff ditches and inter-cropping to prevent upland erosion (Carver, 1995). A cultivation technique involving redistribution of the soil at least in alternate years will improve the nutrient status of the soil and reduce tillage erosion (Quine *et al.*, 2000). The vegetative cover and surface soil condition are important in shaping erosion levels (Carver and Nakarmi, 1995). Cultivation of perennial grass or legumes alternating with grain crops offers good ground cover and could possibly be an effective technique for conserving soil and soil fertility in sloping cropped fields. Ploughing, crop planting and intercultural operations are performed at different times in different crop strips. This avoids exposure of the soil surface and loosening of soil at the same time in the whole field. Plant cover close to the ground, small-leaved canopies and crop residue or litter covering the surface layer help to reduce soil erosion by absorbing some of the rainfall's kinetic energy (Morgan, 1995). A surface mulch of straw is effective at reducing runoff and erosion compared with a conventional non-mulched system (Kwaad *et al.*, 1998). The planting of a perennial forage crop in a rotation plays an important rôle in managing runoff and controlling erosion in hilly area (Chisci *et al.*, 1989). Bare soil surfaces produce up to

91% runoff from incident rainfall, irrespective of the rainfall dimension, whereas grass covered surfaces show 17% runoff of the total rainfall (Chatterjea, 1999). The use of barrier plants from local sources planted on the terrace riser might help minimise nutrient loss through runoff and leaching under high rainfall, especially in the bench terracing system where few other options are available. Land use planning and agronomic measures along with indigenous soil conservation measures are considered as options for improving existing land management (Turkelboom *et al.*, 1997). The diversion of run-on could minimise sediment and nutrient runoff loss. Indigenous soil conservation measures rarely control erosion but can be modified and more efficiently and rapidly implemented than imported technology. Farmers select a conservation technique based on erosion controlling efficiency, short-term benefit, degree of competition with the crops and ease of implementation (Turkelboom *et al.*, 1996).

1.8 PROBLEMS IN SOIL FERTILITY

Soil fertility in all types of terrace systems is decreasing in the middle hills of Nepal. Turton *et al.* (1995) reported the farmers' views on changes in soil fertility in the *bari* land. The main reasons given by farmers for decreasing soil fertility were soil erosion and decreases in forest resources associated with changes in livestock management. The livestock population has decreased leading to a reduction in the production and use of FYM and hence increases in the use of chemical fertilisers. Decreasing labour availability and changes in cropping intensity were other reasons given for soil fertility reduction. The problem of decreasing soil fertility is becoming complex due to a lack of proper training for the farmers on soil and soil fertility protection. Soil erosion is a serious global problem. There are difficulties in accessing reliable and precise measurements of magnitude and rate of soil erosion and of its economic and environmental consequences. The information available is mostly based on surveys (Lal, 1994). However, many farmers rarely consider erosion to be a major agricultural problem (Turkelboom *et al.*, 1996).

Inorganic fertiliser is not easily available due to a limited market and generally poor transportation facilities in the middle hills. The limited amount which is available is not cost effective and most farmers find it unaffordable. Inorganic fertilisers cannot maintain the productivity of maize and millet and the use of organic manures is necessary to maintain productivity in the long run (Sherchan and Gurung, 1995). A reduction in the availability of manure increases bare and marginal land prone to higher runoff and soil erosion. Erosion is regarded as the major factor causing a decrease in soil fertility on *bari* land of the high and middle hills (Vaidya *et al.*, 1995). The process of erosion and deposition affects the soil carbon distribution and drastically alters the biological process of mineralization in the soil resulting in a net loss of carbon from soil systems to the atmosphere (Gregorich *et al.*, 1998). Erosion not only decreases soil fertility but also increases environmental pollution. The main factors causing soil fertility degradation in the hills are the loss of surface soils through runoff, loss of plant nutrients through leaching, sloping land and cultivation systems and nutrient exhaustive cropping systems.

1.9 PURPOSE OF THIS STUDY

The purpose of this study is to develop technologies that farmers will adopt to minimise soil and nutrient loss through runoff and leaching in order to reduce soil erosion under *bari* land conditions in the middle hills of Nepal. A wide range of more profitable and less demanding conservation technologies need to be adopted by farmers (Cramb *et al.*, 2000). Farmers' participation in soil conservation activities encourages other farmers to extent these activities amongst the large numbers of farmers. Such participation resulted in trees growing on terrace risers, bare lands, grasslands and also in the communal grazing land in a different watershed conservation and development project area (Acharya, 1999). Watershed management emphasizes tree planting and gully and torrent control on bare land. However, little attention is given to the million hectares of food crop-producing fields from where most of the pre-monsoon soil loss occurs before development of weed ground cover. This study builds on the studies of Gardner *et al.*, (2000) who concluded that soil loss is less than 1.0 t /ha from terraces and that leaching through the root zone is the pathway through which most nutrients such as K and N (as NO_3 - N) are lost. They emphasize the need for verification of the leaching pattern, which could conclusively explain the mechanism of nutrient leaching loss. There are a number of crops including soybean and rice bean which reduce potential erosion and nutrient leaching (Acharya, 1999). They can be grown as cover crops with maize. Soil loss is up to 48 mm/year with traditional crops compared with 0.03 mm/year with mulching on a 50% slope (Smolikowski *et al.*, 2001). The application of a mulch of weeds or straw and zero tillage prevents erosion (Wild, 1993). Mulching in the ginger crop gives a protective measure against soil loss as well as having economic value. Hence the objective of this study is to enhance farmers' understanding and adoption of soil, water and soil nutrient conservation techniques, which have flexibility in their implementation.

1.10 THE SPECIFIC OBJECTIVES OF THIS STUDY

1. To investigate the effect of strip cropping in minimising fertile soil loss by runoff in the sloping cultivated *bari* lands.

2. To investigate the effect of different crop strips and cropping systems prevailing in the area on leaching loss of nutrients.

3. To investigate the effect of run-on control in high rainfall areas in minimising soil and soil fertility loss through runoff and leaching.

4. To assess the effect of grass planted as a barrier for nutrient leaching and surface soil transportation.

5. To evaluate existing cultivation systems for soil fertility maintenance in an area of the citrus growing pockets.

CHAPTER 2

BACKGROUND

2.1 SOIL FERTILITY MANAGEMENT RESEARCH

Natural resource conservation is becoming a global interest. Soil and water play a key rôle in agricultural production and are nature's gift to man (Bennett, 1955). Soil contains nutrient elements and supports plants grown for food. An adequate supply of nutrients and favourable conditions are needed for the soil fertility potential to be met for sustainable crop production (Buol *et al.*, 1974). Soil fertility maintenance is achieved when the appropriate nutrients are applied at an optimum level for normal plant growth and higher crop yields (Mugwira and Nyamangara, 1998).

Protection of existing nutrients in the soil is another method for maintenance of soil fertility. Plants do not completely take up applied nutrients and nutrient residues accumulate in the soil thus increasing the soil fertility potential of fields for the next crop. The removal of plant nutrients (including uptake by plants) induces a decrease in soil fertility unless they are replaced. With limited resources efforts are made to reduce the unwanted loss of plant nutrients from fields.

There are a number of factors influencing soil fertility and sustainable crop production. The main factor affecting soil fertility is soil erosion caused by heavy rainfall during the rainy season. A proportion of rainfall water is absorbed by soils and the remaining water moves downslope on the surface contributing to runoff and soil erosion (Morgan, 1995). Water enters the soil and passes through soil pores carrying water soluble nutrients beyond the root zone. Excess water moving over the surface and percolating from the root zone therefore plays a major rôle in the reduction of soil fertility and hence crop productivity. The world's arable land area has increased by 9% against a 55% population increase (Craswell, 1993). 10% of cropped land has been severely degraded under irrigated conditions. 30% of cropped land has been severely degraded under rainfed conditions. An overview of the present global soil fertility management situation and assessment of soil erosion hazard can give direction in the planning for soil fertility improvement and conservation in the future.

2.2 GLOBAL SOIL EROSION AND ITS MEASUREMENT

The global land area affected by soil erosion is 1094 million hectares of which 751 m ha is severely affected (Lal, 2003). Erosion causes soil and plant nutrient loss from cultivated lands. Loss of organic matter affects productivity and carbon dynamics. Erosion tends to remove light organic matter causing a severe depletion of the soil organic carbon pool and increases the risk of changing carbon composition from organic form to elemental form leading to pollution. Efforts are continued in research and development of control measures of soil erosion in the world. Pretty and Shah (1997) listed the successful technologies and approaches employed to increase yields and to conserve soils in different countries. New forms of collective action taken by farmers linked formally with existing institutions (including policy makers at a national level) have tackled local environmental problems in Australia, India, Philippines, Kenya, Burkina Faso, Lesotho and Malawi.

2.2.1 Global soil erosion rates

The continent of Asia has the highest rate of soil erosion (16.6t/ha/yr) followed by South America (9.3 t/ha/yr), North and Central America (7.3 t/ha/yr), Africa (4.7 t/ha), Europe (4.3 t/ha/yr) and Australia (3.2 t/ha/yr) [El-Swaify, 1993].

China is the most severely eroded country in the world (20% of the world's total soil loss) [Dazhong, 1993] and erosion rate is highest in cultivated and bare lands. The erosion rate ranges from 150 to 200 t/ha/yr in cultivated lands and from 280 to 360 t/ha/yr in bare soil. An average of 138 kg of organic carbon, 37 kg of N, 0.4 kg of available P and 3.3 kg of K are lost from each hectare of cropped land. Walling (1994) reported that there was a 535 t/ha/yr sediment loss from a watershed area (3199 km^2) of the Huangfuchuan river in mainland of China despite soil conservation technologies in practice in the country. Fu *et al.* (2000) observed that inappropriate land use was one of the main causes of soil erosion and nutrient loss in the hilly Loess area of China. The effect of land use changes on soil erosion and distribution of soil nutrients in the Yangjuangou catchments (having a typical hill and gully topography) was studied. During 1984-1996 forest and grassland increased by 36% and 5% respectively and the slope of farmland decreased by 43 %. Changes in land use decreased annual soil erosion by 24%. Thailand has 30% of its land under sloping agriculture and forest. This land is susceptible to degradation (a decrease in plant nutrients, organic matter and good tilth in the root zone) through rapid loss of topsoil (Sombatpanit, 2001). Less than 12.5 t/ha/yr of soil is lost from 66% land area, 12.5 to 125 t/ha from 30% of the land area and more than 125 t/ha from 4% of the land area. In India 167.08 million hectares of land are affected by erosion of which 77.88 million hectares is under rainfed conditions and the rate of annual soil loss through erosion is estimated to be 16.35 t/ha/yr (Singh *et al.*, 1991). Soil erosion by water has an effect on 113.3 million hectares of agricultural land out of 328 m hectares of geographical land. 2.5 cm of fertile topsoil along with 5.37 to 8.4 million tonnes of plant nutrients are removed from cultivated land each year (Khoshoo and Tejwani, 1993). There is a severe soil erosion problem in West Africa, especially where natural vegetation cover has been removed and annual rainfall is 500-1000 mm. Soil erosion occurs at a rate of 20 t/ha/yr from bare land, 10-50 t/ha/yr from cropped land and 10 t/ha/yr from forest land. Amongst the factors causing soil erosion in these areas are land use and management. Soil types susceptible to erosion and climatic conditions have an accelerated erosion rate. Measures undertaken to ensure proper land use and soil management are found to reduce soil erosion (Lal, 1993). In Ethiopia 13.1% of land is cropped in which soil loss occurs at a rate of 42 t/ha/yr. 3.8% of land is totally degraded, soil loss occurring at the rate of 70 t/ha/yr. The grazing/browsing land occupies the highest area (51%) and soil loss from this is 5 t/ha/yr. This country has 3.6% forest land, 1.7% perennial crop land and 18.7% uncultivated land in which soil loss occurs at a rate of 1 t/ha/yr, 8 t/ha/yr and 5 t/ha/yr respectively (Hurni, 1993). Soil loss occurs less from the forest land than from cropped fields. However, soil loss is highest from the degraded land. An increase in the population has caused deforestation and an increase in agricultural land, increasing soil loss and land degradation unless proper soil management is employed.

In the U.S.A. and Ethiopia erosion losses affect not only fertility of cultivated fields but also reduce storage capacity of reservoirs through the deposition of sediments. Sediment yields of 0.15 to 0.26 t/ha/yr are obtained and 2.0 to 4.0 cm/yr of this sediment are deposited within reservoirs in the upper Kaleya catchments of Zambia (Walling *et al.*, 2001). In Argentina 1660 thousand hectares of land are affected by soil erosion caused by water of which 120 thousand hectares are severely affected and soil losses are more than

121 t/ha/yr. The remaining land losses soil at a rate of 31-120 t/ha/yr (Molina Buck, 1993). The soil erosion rate in Britain varies from 0.1 to 47.8 t/ha/yr and the higher rates are confined to a small area (1-5 %). Some practices increase the susceptibility of agricultural soils to erosion (Arden-Clarke and Evans, 1993). These practices include continuous arable cultivation, conversion of grassland to arable crop land, increasing cereal crop area, use of heavy machinery, removal of field boundaries, and working land upslope and downslope. 45.4% of eroded fields are under cereal crops and 43.1% are under bare land. Soil erosion by water is less than 1 t/ha/yr in 73.6% of the area of Poland and only 5.6% land area has a soil erosion rate of more than 1 t/ha/yr (Ryszkowski, 1993). The annual loss of mineral fertilisers from Poland are 17500 tonne of N, 4300 tone of P and 25000 tone of K. The eroded areas in Taiwan are composed of sandstones, shale colluvial soil and shale alluvial soil. Rainfall occurs mainly in the summer causing serious soil erosion problems (Suchin and Chunbung, 2002). In Australia 520 million hectares of land (51% of the total land area) is under agriculture (Edwards 1993). 28% of the total land area in the arid zone requires soil erosion prevention measures and 32% of the total area of the nonarid zone requires such measures. Erosion rate varies from 31.3 to 87.0 t/ha/yr on bare land and from 0.1 to 16.0 t/ha/yr on cropped land. A maximum erosion rate of 1.9 t/ha/yr is found in pastureland and a maximum of 8.0 t/ha/yr in bushland in Australia.

The erosion rate varies with land type (e.g. natural vegetation, cultivated and bare land). It is always less under natural vegetation but it varies in cultivated and bare land in different countries depending on other factors. In U.S.A. and Ethiopia erosion rate is higher in cultivated land than in bare land. In Belgium and UK there is a higher erosion rate in bare land. The highest rates of erosion in China are under both cultivated and bare conditions. In India the rate of erosion under cultivated land varies from 0.3 t/ha/yr to 40 t/ha/yr (Morgan, 1995).

2.2.2 Global measures of soil erosion control

In China planting of trees, shrubs and grasses reduces soil loss on 10-35° slopes [Dazhong, 1993]. Contour ridge cultivation, pit cultivation and crop rotation reduce soil loss by 60 - 90% in crop cultivation on slopes less than 7°. The most effective measure to control soil loss from cropped land (with less than a 25° slope) is terracing but it takes 750-900 working days to construct terraces on one hectare of land. McLaughlin (1993) presented results on the effect of crop rotation on soil erosion in China (Dingxi County in the Gansu Province). Three year crop rotation of bean with winter wheat gave soil loss of 3.12 t/ha, bean with oats gave soil loss of 16.7 t/ha and soybean/corn gave soil loss of 0 t/ha. This indicates that the legume crop (bean) experiences less soil loss and soybean and, when intercropped with corn, completely prevents soil erosion.The survey of Chuanziying, a typical village south of Tianjin in China, showed that a sustainable agricultural programme on soil conservation has a positive effect on the rural economy by providing ecological, economic and social benefits (Qu *et al.*, 1998). Messing (2001) studied catchments on the Loess Plateau in northern China. He found that farmers were dependent on subsistence agriculture on land of topographic variation and that arable cropping on steep slopes brought about degradation of land due to soil erosion. He stated that grassland is more beneficial than woodland on south facing sites. Slope aspect should be the criterion used in evaluation of suitable land for arable crops. Farmers are able to give a comprehensive picture of the importance of land use options based on land properties but further research is needed concerning slope aspect, soil workability, flooding hazard and the criteria on which farmers base their choice of land use. Grassland and forest are found to have a better capacity for soil conservation in foothills through to hilltops in the Loess area of China (Fu *et al.*, 2000). Contour cropping reduces soil erosion and its effect is more than 6 times that of up and downslope cropping (Jianguo and Chacha, 2002). Small square basins for fruit trees in mountainous areas improve water storage capacity, increase fruit tree survival and productivity (Chen and Lingqin, 2002). Alley cropping and application of balanced fertilizers are employed to reduce soil erosion and increase crop yields compared with levels achieved using farmers' practices in sloping lands (Sajjapongse *et al.*, 2002). Alley cropping can be practiced in sloping lands to minimise runoff volume and sediment concentration. It reduces soil loss from 100 t/ha/yr to 5 t/ha/yr in farmers' fields where leguminous shrub hedgerows are planted in an alley of 5 m width on a hill slope in the Philippines (Paningbatan *et al.*, 1995). Thailand has identified some technologies that improve degraded land. These are vegetative erosion control, bench terracing, hillside ditches, contour grass strips and agroforestry (Sombatpanit, 2001). In India catchment areas with high forest cover (50%) in Srikot Gad experience low runoff (18% of the annual rainfall) and low sediment loss (4.69 t/ha/yr) compared with other catchment areas of low forest cover in Dugar Gad (41.3% runoff and 9.13 t/ha/yr sediment loss). Thus the land use system governs the hydrometeorological parameters of catchments to a large extent (Joshi *et al.*, 1998). Singh *et al.* (1997) reported the use of graded bunds, gully control structures, contour cultivation, intercropping and cover crops in rotation with other practices in the semiarid southeastern Rajasthan of India. Ginger grown in an alley give a higher yield (24.5 t/ha) in the Varada Watershed of Karnatka state in India (Koppad *et al.*, 2001). Maize with a straw mulch reduced soil loss from 18.0 - 22.9 t/ha/yr to 3.6 - 11.4 t/ha/yr from bare land in the plains of the Punjab, India (Khera and Singh, 1998). Terraces, rock barriers and hedgerows reduced soil loss by 80, 78 and 68% respectively on steep slopes ranging from 25 to 60% in upland and agroforestry areas in the Philippines. Hedgerows were observed to be the least expensive option (Dono, 1994). In the central plateau of Burkina Faso farmers use the traditional practice of mulching which reduces soil erosion. However, scarcity of grass for mulching is a problem (Slingerland and Masdewel, 1995). Reduced tillage could protect soil from erosion because crop residues would remain undisturbed on the surface compared with deep ploughing (use of the chisel plough). Deep ploughing is more sustainable over long periods in the northern corn belt in U.S.A. (Pikuljr *et al.*, 2001). Research results from midwestern and southeastern U.S. silt loam soils confirm that soil organic matter contents gradually increase and runoff decreases when no tillage is carried out. This is because greater porosity develops and aggregate stability is enhanced at the soil surface which results in a reduction in surface sealing leading to an increase in infiltration rate (Rhoton *et al.*, 2002).

The aim of the Brazilian National Water Agencies is to conserve national strategic water supply resources thereby reducing non-point source pollution through the incentive of management practices, providing environmental benefit (Domingues, 2002). Brazilian National Water Agencies provides funding for critical watersheds and monitors the effectiveness of the project. Mass mobilization is the key to success for eco-construction and it is a principal part of environmental control. Crop planting in contours prevented a lot of soil erosion in an area of 1009 mm rainfall in Argentina (Molina Buck, 1993). Earth dams and diversion trenches are used to reduce runoff at vulnerable sites with the help of a risk prediction map during climatic changes (when there is an increased the risk of flooding). Land use change in combination with small dams is effective in eliminating the risk of flooding especially on the eastern South Downs in the UK (Boardman *et al.*, 2003).

Soil conservation in Poland is achieved by maintaining forest and shelter belts over 50% of the land area (Ryszkowski, 1993). Arable land is kept below 25% (in which cereals cover less than 45% and root crops cover 15% of the arable area). Priority is given to orchard plantation on slopes.

Research results indicate that the erosion process cannot be completely stopped. However, soil conservation can be achieved by avoiding tillage. This reduces soil loss to an acceptable level on stagnic luvisols in central Croatia where tillage is employed across the slope (Basic *et al.*, 2001). A study of rainfed almond plantations in Spain suggests that a low plant density having a large area of bare soil increases the risk of erosion. A sustainable almond monoculture has a density of 204 trees/ha, allowing rainfall to penetrate deep into the soil in a semiarid climate (Wesemael *et al.*, 2003). The careful selection of an optimum erosion preventive ecosystem with a high erosion resisting capability assists erosion control and ensures the ecological stability of the undulating topography of Lithuania. A grass/grain crop rotation increases soil aggregate stability on sloping land (angle 10-14°) and decreases soil erodibility (Jankaushas and Jankauskiene, 2003). Green manuring and cover crops have increased yields with less of a labour (ploughing and weeding) requirement in Brazil (micro water shade programme) and Honduras. Research results from regosols in the south of France, nitosols in Benin, ferralsols in Cameron and regosols in Mexico, and from a semi-quantitative assessment of the frequency of erosion features on vineyard hillsides in southern France confirms aggregate stability to be a relevant indicator of soil susceptibility to runoff and erosion especially in Mediterranean and tropical areas where frequent intense rainfall occurs (Barthés and Roose, 2002).

2.3 SOIL EROSION AND ITS MEASUREMENT IN NEPAL

The Department of Soil Conservation in Nepal was established in 1974. Its objectives were to conserve and develop different watershed areas by minimising flooding, landslides and soil erosion (Anon.,1995/96). This department began various watershed management projects such as the Bagmati Watershed Project, Community Development and Forest/Watershed Conservation Project (including Greenery Co-operation Promotion and Western Hill Integrated Watershed Management), Kulekhani Watershed Project, Begnastal Rupatal Watershed Conservation Project, Environment and Forestry Enterprise Activity, Upper Adhikhola Watershed Management Project and the Inter Regional Upland Conservation and Development Project. In addition, this department developed policies and strategies for watershed management and soil conservation. Plantation of forest, fodder and fruit trees, river bank protection, construction of water collection ponds and terrace improvement programmes were conducted at different places and during different periods.

Watershed management is complex and its rôle is confused with agriculture, forestry, integrated land development and upland conservation (Wagley and Bogati, 1999). However, it has been practised under soil and water conservation and different watershed management programmes. There are several other projects which contribute to the development of technologies and their extension in Nepal. The Jhikhu Khola Watershed Management Project was established in 1989. Its main aim was to pinpoint the major processes causing degradation of natural resources (e.g. soil erosion causing land degradation). In addition successful land use practices to develop other parts of the middle mountain using the basic information from the Land Resource Mapping Project (conducted between 1978 and 1984) were identified (Shah and Schreier, 1995). About 85 % of households in the Jhikhu Khola watershed cultivate more than 84 % of rainfed land (including *bari* lands). The main problem for farmers is the lack of irrigation water for sufficient food production (Shrestha and Brown, 1995). In the Jhikhu Khola Project area, *bari* land is increasing in area from shrub land and grazing land where the slope is greater than 20 %. These lands have poor fertility. This indicates a move towards agriculture marginalisation (Shrestha and Brown, 1995). Carver and Nakarmi (1995) explain that the factors affecting soil erosion rate are rainfall intensity and surface condition (e.g. tillage, vegetative cover, soil moisture, land use and degradation). These are often interrelated. Soil losses are large when intense rainfall occurs and there is inadequate surface cover. Soil properties also affect soil erosion rate. Carver and Shreier (1995) concluded that the management techniques in the Jhikhu Khola Watershed were effective in avoiding sediment loss during the monsoon season. They also concluded that the pre-monsoon season is a period of vulnerability, high soil and nutrient losses being likely due to the lack of vegetative cover. Carver (1995) classified indigenous techniques employed by farmers to prevent erosion from the fields as either 'on field' or 'off field' methods. 'On field' methods include terracing, runoff ditches, intercropping and fertility maintenance. The 'off field' methods include the management of runoff from upland to irrigated fields by silt traps in the irrigation system, making fields fertile.

The land in the middle mountains is degraded as a result of extreme surface erosion due to poor surface cover (Carver and Nakarmi, 1995). Carson *et al.* (1986) described the erosion process and estimated sediment and nutrient losses from different land use systems in Nepal. The erosion process consists of natural and accelerated erosion. Mass wasting and landslides are different forms of natural erosion. The natural erosion rates are extremely high because of the constant tectonic uplifting of the major mountain ranges and downcutting of the river system to give the present shape of the landscape in Nepal. The losses of topsoil through sheet and rill erosion are different forms of accelerated erosion. Rainfall erosivity, soil erodibility, slope length, steepness and cropping systems (including natural vegetation) are the factors contributing to surface erosion.

Turton *et al.* (1995) reported that there are two main types of land: poorly managed sloping terraces where soil loss is 20 to 100 t/ha/yr and degraded range land where soil loss is 40 to 200 t/ha/yr. There are four different land use systems: irrigated rice land, level terraces, sloping terraces and shifting cultivation. There is no soil loss or nutrient loss through runoff from irrigated rice land. The estimated losses of nutrients through eroded sediments from the last 3 systems are: 150 kg/ha/yr organic matter, 7.5 kg/ha/yr N, 5 kg/ha/yr P and 10 kg/ha/yr K from levelled terraces; 600 kg/ha/yr organic matter, 30 kg/ha/yr N, 20 kg/ha/yr P and 40 kg/ha/yr K respectively from sloping terraces, and 3000 kg/ha/yr organic matter, 150 kg/ha/yr N, 100 kg/ha/yr P and 200 kg/ha/yr K respectively from shifting cultivation. Farmers are acutely aware of the erosion problem in Nepal and that erosion causes the most potentially serious loss of topsoil and nutrients. Annual application of farmyard manure and compost replaces these nutrient losses. Farmyard manure application to *bari* lands is the main source of plant nutrients (Vaidya *et al.*, 1995). The amount applied varies depending on the crop grown and its proximity to the homestead. Therefore *bari* soils have a higher level of organic carbon, total N, available P and exchangeable K than the *khet* land. Erosion is identified as a major contributing factor to the decline in soil fertility, particularly at mid and high altitudes.

The *bari* land is likely to be more prone to soil loss than most other land as it has limited ground cover for part of the monsoon season. South facing subcatchments have a lower soil organic matter content and a weaker soil structure and are therefore prone to soil erosion (Gardner and Harmer, 1995). With the increasing marginalisation of *bari* lands where irrigation is not possible, soils are thin revealing a silty and sandy subsoil that is potentially highly erodible.

On cultivated rainfed lands most of the soil loss occurs in the early monsoon before the weed ground cover has fully developed and when ploughing accelerates the process by disaggregating and loosening the soil (Gardner *et al*., 1995). Another sensitive period is mid to late August, at the time of maize harvest and millet planting, when monsoon rain can still be highly erosive. Nutrient balance is most critical in rainfed maize production where 94 % farms are in deficit and reducing erosion is one option (Brown *et al.*, 1999). A report was published that inward sloping terraces suffered less soil loss compared with outward sloping terraces, terraces with contour ridges and hillside ditching (Anonymous, 1991). However, maize yield remained low on inward sloping terraces. The report indicates that mulching is effective in reducing soil runoff loss. Further studies on soil and water conservation were recommended involving the consideration of the cropping system and the analysis of nutrient loss (especially nitrate) through runoff water.The estimation of soil and nutrient losses as well as effort put into their conservation has been evaluated under different land use systems and watershed management projects in Nepal. National average yields in most of the Hindukush-Himalayas have stagnated and show a downward trend because soil nutrient deficiencies are widespread (Allen, 2001). Results of survey and research work in Nepalese watersheds during 1997 and 1998 show agricultural intensities and primary nutrient problems. There was low availability of phosphorus due to poor distribution of P in bedrock, acidic soil conditions and presence of a high quantity of amorphous Fe and Al in the red soil. Moreover, poor quality organic matter in the soils and leaching of base cations have enhanced the depletion of soil nutrients.

The United Nations declared 2002 the International Year of Mountains in order to raise awareness about the importance of mountains and to contribute to their development by ensuring harmony amongst the human beings in mountainous regions (Shakya, 2002). Ten per cent of the world's population live in mountains where the environment is deteriorating. Soil is one of the natural resources and its decreased fertility affects production. Fertility management in hills through soil and water conservation could contribute to one of the aims of the International Year of Mountains 2002.

The present watershed management policies and strategies of Nepal involve the implementation of integrated programmes that include vegetative and agronomic measures to tackle erosion problems taking the subwatershed area as the unit of planning and management. They also involve the establishment of links and networking with all other related sectors such as forestry, agriculture and livestock farming, taking into consideration water and land resources, participation of people in technology development, extension, education and demonstration, watershed protection near hydroelectric dams, irrigation systems, riverbank plantation and other conservation techniques. They focus on conservation activities in the fragile Siwalik area and other marginal lands, and institutionalise services in all districts of Nepal (Department of Soil Conservation and Watershed Management: a bulletin). The Department of Soil Conservation and Watershed Management has developed some programmes for the participation of people through formulating user groups to carry out different activities for soil conservation and watershed management. The ninth five year plan reported that His Majesty's Government of Nepal realise that participation of people in soil and water conservation activities sustain soil conservation and watershed management. The Department of Soil Conservation and Watershed Management has published a bulletin stating the importance of protective crop cultivation (use of water management, land management, crop management and improvement of soil fertility). A number of bulletins were published by the Department containing different slogans, helping to motivate people to natural resource conservation. A conservation newsletter is regularly published outlining different activities related to soil and water conservation in the country. The Soil Conservation Department has developed a strategic plan to provide information to the technology user's group in watershed and sub-watershed areas and helps farmers by providing funds for their economical development. The Soil Conservation District Office has launched farmers' group work in soil conservation in the Tanahu district. The farmers' group receives funds from the office and plans its work. Fodder crops, trees and grass planting in terrace risers are on the increase (Shreshtha, 2002). Dev (2002) published a booklet advising farmers to use bioengineering techniques, in which local resources (e.g. bamboo and loose stone) are used in the construction of check dams to control soil erosion. Besides the Department of Soil and Water Conservation and Watershed Management there are different international and national nongovernmental organisations developing technologies for natural resource conservation.

Gardner *et al.* (2000) carried out a study from 1996 to 1998 to assess soil erosion and nutrient loss in the middle hills at the Western Development Region of Nepal. They concluded that relatively low soil erosion occurred in the monsoon season (less than 5 t/ha/yr) and that the majority of rain falling on soil infiltrates to depth, runoff usually accounting for less than 10 %. They observed much less nutrient loss from runoff and erosion than from leaching. Loss of soils through runoff was estimated to be 0.25 to 4.1 t/ha/yr from cultivated bench terraces at Landruk (receiving 3354-3626 mm rainfall), 0.1 to 12.8 t/ha/yr from sloping wide terraces at Nayatola (receiving 968-2590 mm rainfall) and 0.3 to 35.4 t/ha/yr from bench terraces at Bandipur (receiving 1261-1606 mm rainfall). The loss was much higher from the plot receiving run-on. The loss of N in the form of nitrate in leachate was estimated to be about 5-20 kg/ha/yr from Landruk, about 25-44 kg/ha/yr from Nayatola and about 5-20 kg/ha/yr from Bandipur. Similarly, loss of K through leaching was estimated to be about 50-90 kg/ha/yr from Landruk, about 40-170 kg/ha/yr from Nayatola and about 25-265 kg/ha/yr from Bandipur.

Previous studies show that soil erosion is still a problem in the sloping lands and conservation studies and development are continuous. Rainfall is the major cause of soil erosion and nutrient loss, affecting soil fertility and crop productivity in the hills of Nepal. Erosion control measures must be employed in cultivated *bari* lands which begin soil erosion and are decreasing in fertility. Crop, land and water management are important components of research into and development of soil fertility in the *bari* lands.

Existing studies are found in two projects: Incorporation of local knowledge into soil and water management interventions which minimise nutrient losses in the middle hills of Nepal (DFID R7412) and assessment of strip cropping against soil and soil fertility loss in the sloping *bari* lands in the Western Development Region of Nepal (HARP pp. 14/99). DFID R 7412 focussed on the evaluation of interventions through scientific measurement of their effect on soil and nutrient loss. DFID has provided funds of more than 5 million rupees through the University of Bangor to ARS, Lumle to conduct research work in the middle hills. HARP pp. 14/99 focussed on the evaluation of strip cropping as a system for sloping cultivated lands in the middle hills. HARP provided funds of more than 3 million rupees through NARC to ARS, Lumle to conduct research in sloping cultivated lands. The aim of both projects was to develop soil conservation technologies through the sharing of the knowledge (eg. farming systems susceptible to soil erosion including the *bari* lands of the Western Development Region of Nepal) between researchers and farmers.

2.4 SOIL FERTILITY MANAGEMENT IN SUBTROPICAL AND TEMPERATE HILL ENVIRONMENTS

Soil organic carbon in 0 – 7.6 cm soil depth is increased as tillage intensity decreases because tillage creates a more oxidative soil environment for rapid decomposition (Halvorson *et al.*, 2002). Adoption of an appropriate conservation practice reduces soil organic carbon losses (Lal, 2003). Loss of carbon further increases the erosion susceptibility of the soil. Owens *et al.* (2002) observed a soil carbon loss ranging from 12.7 to 24.0 kg/ha/yr under different tillage systems. An increase in the amount and depth of tillage causes an increase in carbon loss. Organic matter content in the soil is an important indicator of soil fertility (Chenge *et al.*, 2002).

Gregory and Pilbeam (2000) showed a flow diagram of losses of 5.3-18.0 kg N through leaching from each household in the middle hills. However, land areas were not mentioned. They also showed that N gained by run-on is equal to the N lost through runoff. A low level of NO_3-N leaching occurs in well managed catchments (Kortelainen, 1998). N loss by leaching is determined by rainfall. 25 % of the input is found to be leached in the Cotswold Hills, England (Allingham *et al.*, 2002). A mulched tillage system yields less nitrate in leachate compared with a ridged tillage system despite similar chemical inputs and similar amounts of leachate from both systems but the extent of leaching may be site-specific (Kitchen *et al.*, 1998). In a study analysing nitrate in leachate from the crop root zone, nitrate nitrogen (NO_3-N) concentrations were determined in soil samples collected in two consecutive years (1995 and 1996) in Nova Scotia, Canada . Samples were collected at 4 depths and from two sampling locations over shallow and deep drainage tiles on 5 sampling dates throughout the growing season. Results suggest that NO_3-N concentrations in the soil depend on the sampling depth, the sampling date, and subsurface drainage depth. At the shallowest soil sample depth (0-150 mm) soil NO_3-N concentrations were low at the beginning of the growing season, increased after fertiliser/manure application in late May, then gradually declined through winter up to the start of the next growing season. At 600-900 mm depth NO_3-N concentrations remained low throughout the year. In both years, soil contained more NO_3-N when the drainage tile was deep (800 mm) compared with when it was at a shallow depth (500 mm) [Astatkie *et al.*, 2001].

Despite the high adsorption rate, biologically available P (from decomposed plant material) is lost with sediment (McGechan, 2002). Soil erosion is the major mechanism for P mobilization and transport (Hollinger *et al.*, 2001). Wallbrink *et al.* (2003) found a low P content in cultivated soil compared with forest soil possibly due to the export of P with crop materials in cultivated land. Lal (1993) found that a maximum of 3.7 kg/ha/yr PO_3-P was lost in runoff from bare fallow land and a maximum of 20 kg/ha/yr Bray-P was lost with sediment. Wither *et al.* (2003) suggest that slurry application in splits reduces P export in runoff up to 60% compared with basal application in the maize fields. Infiltration rate decreases as rainfall intensity and its kinetic energy increases because of seal formation in the soil, hence K leaching decreased (Shainberg *et al.*, 2003 ; Wang *et al.*, 2002).

Water stable soil aggregates decrease in continuous corn fields and increase from 23 % to 40 % in the field when legumes are grown in rotation (Rachman *et al.*, 2003). In intercropping systems water stable aggregates may be present in high quantities in the surface soil and enhance leaching (Kumar *et al.*, 2002). Aggregate stability is reduced above 5.8 cm depth in the surface soil due to frequent wetting and drying of the upper surface (Rachman *et al.*, 2003). Moreover, frequent tillage and expose to raindrop impact during the fallow period may increase disruption of soil aggregates. However, an improved soil structure would increase the water holding capacity of the soil and therefore reduce leaching. Land left bare and fallow results in an increase in organic matter mineralisation and nutrient leaching (Ruszkowska *et al.*, 1993). Increased diversity in agriculture (especially in terms of crops and cropping systems) can help to minimise nutrient leaching loss (Main *et al.*, 1999). Soil profile depth and nutrient stocks must be managed in order to prevent soil degradation (Hopkins *et al.*, 2001).In some cases non-legumes were found to be better than legumes (with N fertiliser) at increasing the soil organic carbon and N contents of the soil (Sainju *et al.*, 2002).

Khoshoo and Tejwani (1993) reported that removal of 2.5 cm topsoil decreases maize grain yield by 14 %. However, the effect of soil loss on crop yield depends on the depth of soil. Crop yield will not be affected for 200 years if the soil depth is 2 metres even if soil loss is 25 t/ha/yr (Arden-Clarke and Evans, 1993). Climatic change from year to year does not have a measurable effect on the level of erosion severity or on crop productivity (Arriaga and Lowery, 2003). The benefit cost ratio increases only in the long run after the introduction of soil conservation practice (Ashok and Ramasamy, 2002). Cucci *et al.*, (1997) reported that inclusion of the field bean in the crop rotation with wheat did not have a significant effect on wheat yields or nutrient leaching. Dwivedi *et al.* (2003) reported that cowpea minimised NO_3-N leaching beyond 45 cm depth in the soil profile when it was planted as a forage crop before rice. Cowpea removed a greater amount of nutrients via the above ground biomass than that recycled through roots and nodules, resulting in less nutrient leaching. Nutrient leaching depends on a numbers of factors including type of crop, soil and management practice. A substantial amount of nutrients is added to soil via rainfall. Loss of soil from uplands (*bari* land) due to runoff benefits the *khet* lands by adding fertility (Grosjean *et al.*, 1995). Farmers apply a large quantity of farm yard manure to *bari* land than khet land. The average application of FYM is 19.2 t/ha in uplands in the Phewatal watershed area (Thapa and Paudel 2002). Estimates of NPK balance in upland are negative for N (-21 kg/ha/yr), positive for P (12 kg/ha/yr) and positive for K (37 kg/ha/yr) in the Pokhara area.The loss of N may not be greater than 13-18 kg/ha/yr through denitrification and 15-25 kg/ha/yr through volatilization, values obtained in the Cotswold Hills, England (Allingham *et al.*, 2002).

2.5 CONSERVATION POLICY AND TECHNOLOGY ADOPTION

National policy affects the adoption of technologies for soil water conservation. Excellent government policies and scientific control measures to conserve natural resources attract the local people and greatly encourage mass participation. Community participation and empowerment, appropriate technology, issuing policies, regulation and bylaws are key strategies for the promotion of appropriate soil and water conservation activities (Danano 2002). Erosion control, safe runoff disposal, water retention and fertility improvement are the key routes for conservation. Conservation practices must be effectively implemented with watershed management involving protective rangeland rules, sustainable erosion control techniques and environmental protection policies (Golabi, 2002). Sloping land should not be kept bare. An increase in bare soil from 6.3 to 11.0 % has occurred in semiarid regions as a result of increased pressure from livestock grazing (Kuiper and Meadows, 2002). Qinghua *et al.* (2002) suggest reforestation of farm land having a slope angle > 15° (prone to more runoff and soil loss). The nature and availability of land, socioeconomic constraints, the complex nature of introduced technology and inadequate extension services are all problems in technology adoption.

Technology identification for a particular environment and its adoption is important in order to minimise soil and nutrient loss. Research work in sites representative of the major agroecological regions of the Western Development Region and farmers' participation helps in the process of technology evaluation and adoption. Information obtained can then be applied to a larger area.Technology adoption is the result of different factors such as age, education, resources, social and economic status and needs of the users (Prakash *et al.*, 1998). Neupane *et al.* (2002) observed that technology in agroforestry management tends to be adopted by female in project area and male in non project areas. This indicates that the technology extention programme must be specific to the farm family. The project should explain in detail the onsite benefits, especially short-term benefits creating large differences. A new technology providing less benefit compared with an existing one is insufficient to convince upland farmers to adopt the technology. Conservation practices must be developed through participation involving extension workers, researchers and farmers, taking into account the local biophysical and socio-economic conditions of the upland farmers (Richard and Jose Nestor, 2002)

Implementation of sound soil conservation practices and sustainable farming brings greater profit to the farmers and the nation as a whole in the long run. Sustainability cannot be achieved with the continuous depletion of soil nutrients, severe erosion, land degradation and environmental hazards. Emphasis should be given to the management of sustainable land resources for economically productive purposes. Ninan (2002) observed that a watershed development programme in India motivates farmers to change to the crops and land use systems more suitable for dry regions (e.g. horticultural crops and forest species) than annual crops. The benefit cost ratios or gross return from horticulture, fuel wood and fodder crops are much higher than for annual crops.

There is no generalised technology recommendation as each community has different culture and topography (Shoaib, 2002). Agronomic studies to evaluate the long term benefits of technology adoption and adverse effect of land use changes should be carried out (Varela *et. al.*, 2001). If employed, the technologies should be sufficient for soil and water conservation depending on appropriate application and recognition of local knowledge. Suitable techniques vary from person to person and place to place (Stocking, 2002). Soil fertility conservation is of low priority for farmers and new resource management options need to be developed in line with the farmers' priorities. New economical technologies given priority by the farmers overcome soil fertility decline (Wezel *et al.*, 2002). Erosion control measures at different sites are: terracing of slopes, torrent sediment traps, big pit and interceptor channels, plant barriers, contour strip cropping, contour ploughing and restricting cultivation to allow recovery (by vegetation and forest management) of sloping areas. Changes in climate are challenges in soil conservation because these changes have an effect on soil erosion susceptibility (Meadows, 2003). If erosion susceptibility changes, farmers may have to take a risk with new technologies (even with previously adopted technologies). A variety of technologies must therefore be available to cover a wide range of variability in a domain. Most soil conservation technologies require more than 5 years for benefit to be realised. The investment in soil conservation can be recovered after 5 to 10 years depending on site-specific enterprises (Diwate *et al.*, 2002). This suggests that the cost of soil conservation can be returned after a long period and technology proves beneficial. Farmers can afford to adopt soil conservation technologies only with an incentive at initial stage. Incentives may facilitate adoption and extension of new technologies.

CHAPTER 3

MATERIALS AND METHODS

3.1 SITE SELECTION

This study is concerned with soil fertility research and follows up previous work (1996-1998) on soil erosion and nutrient loss in the middle hills of Nepal. It is funded by the Department of International Development (DFID). In the previous project seven study sites identified as being representative of the middle hills in the Western Development Region of Nepal were selected. They were within the on-farm research testing area of the Agriculture Research Station, Lumle, Nepal. Qualitative parameters of declining soil fertility and nutrient loss were studied at each of these sites. The qualitative parameters measured were sediment depth in troughs, number of events causing erosion of soils, flow lines in terraces and general observations of the visual effect of raindrops on exposed soils (e.g. exposure of underlying stone, roots and depressions). On the basis of these qualitative studies three agro-ecologically representative sites were selected for quantitative studies of soil erosion and soil fertility loss. These were Nayatola in the Palpa district, Landruk in the Kaski district and Bandipur in the Tanahu district (Gardner *et al.*, 2000). These sites differ from each other in terms of land terracing system, rainfall pattern, cropping system, altitude and farm field fertility management. The present study was also conducted at Nayatola, Landruk and Bandipur (Fig 3.1).

3.2 SITE DESCRIPTION

3.2.1 Nayatola

Nayatola is a village situated approximately 30 km west from Tansen, the headquarters of the Palpa district. Annual rainfall is less than in the eastern part of the country and it is therefore a moderate rainfall area. The altitude of the area in which the experimental plots were located ranged from 1100 to 1400 m asl and its aspect is northern/northeastern. The Magar community is the dominant ethnic group of the area. Farmers have adopted a maize-based and nonirrigated sloping land cultivation system in the *bari* land (Plate 3.1). The slope angle of the terraces varies from 5° to 25°. Fertility management of the *bari* land solely depends on the application of farmyard manure (FYM). Farmers prepare manure by mixing cattle dung with leaf litter, bedding materials and left over animal fodder in pits or heaps. Most FYM is applied for the benefit of summer crops particularly prior to the planting of maize. Farmers use bullock drawn wooden ploughs to cultivate their farm fields but most of the intercultural operations are performed manually using a spade. Maize is produced as the staple food crop. Every farmer grows a small area of ginger as a cash crop.

3.2.2 Landruk

Landruk is a village situated on the way to the Annapurna Himalaya base camp, about 15 km north of the Agricultural Research Station, Lumle, Kaski. This is a high rainfall area having 3000 to 3800 mm annual rainfall concentrated in the summer season of March to September. During the rest of the year it is dry and cold. The altitude of the area where the research plots are located ranges from 1400 to 1600 m asl. The cultivated land has a northern/northwestern aspect. The Gurung are the dominant local residents. Farmers have adopted a bench terracing system in fields with a slope angle of less than 5° (Plate 3.2). Maize/millet in yearly rotation with maize/wheat or barley is the dominant cropping system in the *bari* land of this area. Farmers in Landruk practice an *in situ* field manuring system by keeping their cattle on the terraces between harvest of one crop and planting of the next.

3.2.3 Bandipur

Bandipur is a small town in the Tanahu district. It is situated approximately 80 km east of Pokhara and is accessible by a gravel road. It receives a total of 1200 to 1800 mm annual rainfall concentrated in the summer months of May to September. The altitude of the area where the research plots are located ranges from 900 to 1100 m asl. The aspect of the area is both northern and southern. Professionals are a mix of Brahmin, Newar, Magar and others. Farmers have adopted a bench terracing system in fields with a slope angle of less than 5°. This area comprises a unique cropping system of citrus orchard with or without intercropping of cereals and legumes. Other important cropping systems in this area are maize/millet and upland rice/blackgram. The field manuring system is the same as that described for Nayatola.

3.3 EXPERIMENTAL DESIGN

The interventions evaluated in this study were selected by stakeholders at a project stakeholder workshop. Successful work at the regional level, nutrient dynamics at previous research sites and the results of a local survey on soil and water management (Shrestha, 2000) were discussed during the selection of interventions. Research done in Nepal and in other countries was also reviewed and the findings incorporated into the design of soil and water management interventions. Two main interventions were selected for Nayatola and two for Landruk. These were compared with the existing farmers' practice using a completely randomised block design. There were 8 previously established plots in five farmers' field in Nayatola and 9 in five farmers' fields in Landruk. A total of 15 experimental plots including existing plots were established in each site. Each farmer's field was a complete block of treatments. Each block had at least one previous plot which was used as the control treatment. Some of the blocks had 2 previous plots, one was allotted for the control and another was randomly allotted for one of the intervention treatments. Therefore, 3 treatments were replicated 5 times in different blocks assuring a randomised complete block design (RCBD). The existing six plots exhibiting the different cropping patterns in Bandipur were used as a nonreplicated observational study. Each experimental plot was 100 m^2 (5m x 20m). However, in Nayatola each plot contained a single terrace and in Landruk and Bandipur each plot contained 3 to 9 terraces.

3.4 OBSERVATIONS

3.4.1 Rainfall measurement

Rainfall was recorded at all three sites during the rainy season from March to September using both automatic and manually operated rain gauges. The automatic rain gauge consisted of an automatic trip-recording logger which records the time for each tip in seconds. The loggers were changed at one-and-a-half-month intervals and the data were downloaded on to a computer. Cumulative data collected over a period were analysed using the software programme ftn90. Total daily rainfall in mm and kinetic energy produced by rainfall intensity during rainy days as Joules mm/m^2/h and then Mega Jules mm/ha/h were calculated. The rainfall was also measured at all sites using a manual rain gauge. The manual rain gauge was kept in the open field and the volume of the water collected in the rain gauge was measured daily at 8 a.m. A sample of rainwater was also collected weekly for nutrient analysis. The sample was taken from the manual rain gauges on the first day of the week on which it had rained.

3.4.2 Runoff measurement

The standard plot size and method described by Morgan (1995) was followed in order to measure runoff. The experimental plots were enclosed by metal sheets to prevent lateral movement of water into and out of the plot (Plate 3.3). In the case of Landruk, except in the closed plot (run-on controlled), other plots were kept open from the top to allow run-on. The top edge of the metal sheet was about 0.3 m above the soil surface and the lower edge extended 0.2 m below the soil surface. A 5 m long trough was located at the lower end of the plot and connected via a polythene pipe to a drum into which the total runoff from the experimental plot was collected. Three drums were connected to each other in series so that, when the first drum filled, a proportion of water passed to the next drum (Plate 3.4). The first drum in the series had 10 outlets, one of them being connected to the second drum so as to allow one tenth of the water flow from the first drum to the second drum. The second drum had two or 10 outlets depending upon the nature of the treatment plot. If the treatment plot was closed the second drum had only two outlets and, if the plot was open to allow run-on, then the second drum had 10 outlets. The third drum was connected to one of the outlets in the second drum. Water level in the drums was measured in cm and the water level was converted into litres by calibrating the drums with the measured volume of water. The calibration was done for each drum at the end of the rainy season.

The distribution of water through the outlets from drum A to B and B to C was recalibrated and the ratio calculated to give the litre conversion factor for the water in drums B and C. The conversion factors were calculated for drums B and C in all plots. Runoff was measured daily if there was rain during the periods of May 31st to Aug. 24th (2000), April 19th to Sept. 7th (2001) and May 14th to Sept. 25th (2002) at Nayatola, May 16th to Sept. 23rd (2000), March 26th to Oct. 2nd (2001) and March 23rd to Oct. 9th (2002) at Landruk; May 12th to Sept. 9th (2000), May 7th to Sept. 16th (2001) and April 19th to Sept. 27th (2002) at Bandipur. A composite runoff sample was collected weekly for each plot. Nitrate nitrogen, dissolved phosphorus and potassium were analysed and converted into kg/ha for the different periods of the monsoon season and the season as a whole monsoon.

3.4.3 Eroded sediment measurement

The runoff collected in all drums was stirred thoroughly and a 0.5 l sample was taken from the middle of each drum. The sample was filtered and oven dried for 36-48 h to a constant weight at 75° C. Whatman No. 54 filter paper was used to filter the samples. Each filter paper was pre-weighed and the sediment weight determined by subtracting the weight of filter paper. The total eroded sediment weight in kg was calculated from the total runoff volume over the season.

Composite samples of eroded sediment for the whole season were prepared for each plot. Organic carbon, total N, P and K contents in the eroded sediment were determined using the same methods as for the soil samples.

3.4.4 Leachate measurement

In the first year of the experiment one lysimeter was installed in each of the upper, middle and lower positions (Fig. 3.2) of each plot at Nayatola and one in each of the upper, middle and lower terraces of each plot at Bandipur. In Landruk, one lysimeter was installed in each of the upper, middle and lower positions of the plot in one block and one lysimeter was installed in the upper and lower positions of the plot in the remaining blocks. In the second year, additional lysimeters were installed in the intervention plots at Nayatola to give information about the two crops. The completed lysimeter installation at Landruk resulted in the presence of three lysimeters in each plot (in upper, middle and lower terrace positions) in all the blocks. Each lysimeter (Plate 3.5) was constructed and inserted to ensure collection of leachate from the top 40 cm of soil. It was made from a polythene pipe of 11 cm diameter and 25 cm length and was filled with soil having the same profile as that in the field. A leachate collection cup was fitted in the end of the pipe and two small, soft tubes of 5 cm diameter passed out through the pipe, remaining above the soil surface and allowing leachate to be pumped out. The lysimeters were inserted in the fields 15 cm below the surface of the soil.

The leachate was measured during the periods of May 31st to Sept. 24th (2000), May 7th to Sept. 16th (2001) and May 14th to Sept. 25 (2002) at Nayatola. The leachate was measured during the periods of May 16th to Oct. 15th (2000), April 21st to Sept. 24th (2001) and March 25th to Oct. 9th (2002) at Landruk. The leachate was measured during the periods of May 12th to Sept. 9th (2000), June 6th to Sept. 16th (2001) and April 9th to Sept. 27th (2002) at Bandipur.

The leachate was pumped out of each lysimeter using vacuum pumps. The volume in ml was measured in a measuring cylinder. The leachate sample was collected from each plot and bulked on a weekly basis. A 100 ml composite sample was then prepared for each treatment in all blocks. These were kept separately in polythene bottles. There were therefore leachate samples for all treatments and blocks in each week during the whole rainy season. These samples were transported to the laboratory at the end of each week. In the laboratory the samples were filtered through 0.45 μm filter membrane and stored at 5° C prior to analysis of leachate nutrient content. Each leachate measurement was taken from an area (having a 11.0 cm diameter). Values were converted into l/m^2 ($1l/m^2 \equiv 1$ mm). Nitrate nitrogen, phosphorus and potassium contents were analysed and values were expressed in kg/ha.

3.4.5 Field moisture measurement

Moisture content in surface soil was measured at least once a week during lysimeter reading from 2001 onwards at the Nayatola and Landruk sites. A soil moisture theta-probe was used to record soil moisture directly in the field as m^3 water per m^3 soil. Graphs of the relationship between moisture content of the soil and cumulative rainfall were plotted.

3.4.6 Soil sampling and laboratory analysis

In the first year of the experiment a composite soil sample of five cores (5 cm diameter and 25 cm height) was collected from three places ranging from the bottom to top terraces of the plot before the crop was planted. This gave a record of the bench mark nutrient content in the experimental plots. A composite soil sample from each position was regularly taken from all the plots at the end of the rainy season after crop harvest. Soil samples were collected separately from different crop strips (in intervention plots) in different plot positions in the case of Nayatola. There were therefore six soil samples from the cropped strip plots, three samples from the control plot of Nayatola and three samples from each plot at Landruk and Bandipur. A soil auger (core of 5 cm diameter and 25 cm height) was used to collect the soil samples. The five soil cores were mixed thoroughly and reduced to a weight of 0.5 kg to provide a representative soil sample for each experimental plot. These samples were taken to the soil laboratory in the Agriculture Research Station, Lumle. Here they were air dried, ground and sieved through a 2 mm sieve. The processed samples were analysed for pH, texture, potassium and phosphorus content and cation exchange capacity (CEC). A portion of the sample was further passed through a 0.5 mm sieve to allow measurement of soil organic carbon and total nitrogen content.

Soil organic carbon, total N, available P, exchangeable K, pH, and CEC were analysed in the initial soil samples collected from Nayatola, Landruk (Table 3.1) and Bandipur (Table 3.3). Soil particle size distribution were also analysed from Nayatola and Landruk for bench mark records (Table 3.2). Soil samples were also collected from all the sites after each complete crop cycle and were analysed for organic carbon, total nitrogen, available P (Bray), exchangeable K and pH during 2000 and 2001, and additionally for CEC and texture in 2002. These were compared with the initial soil samples.

Soil and water samples were analysed following the procedure described by Anderson and Ingram (1993). These methods are shortly described here. Soil organic carbon was estimated using the Walkey method. The colorimetric method was used to estimate total nitrogen in a spectrophotometer. P was extracted from the soil using the Bray method and estimated by the colorimetric method in a spectrophotometer. Exchangeable K was analysed using ammonium acetate (0.1 m) extraction and a flame photometer. CEC was estimated by using ammonium acetate and potassium chlorite extraction followed by colorimetric analysis in a spectrophotometer (Anderson and Ingram 1993). Soil pH was measured using a pH meter electrode in the soil extract (soil: water ratio of 1:2.5). The texture of the soil samples was determined using the soil hydrometer method. Bulk density was also estimated from experimental plots at the end of the season using soil core samplers (7 cm in height and 5 cm in diameter). Bulk density was calculated based on the oven dry soil weight.

Table 3.1 Mean soil properties analysed before the treatment application at experimental sites (2000).

Sites	pH	OC (g/ kg)	TN (g/kg)	Av. P (mg/kg)	Exch. K (mg/kg)	CEC (meq/100g)
Nayatola	5.7	10.7	1.3	12.9	250.6	52.5
Landruk	5.4	16.7	2.5	56.5	159.0	45.9

Table 3.2 Mean soil particle size distribution analysed before the treatment application at experimental sites (2000).

Sites	Clay (g/kg)	Silt (g/kg)	Sand (g/kg)
Nayatola	198.2	341.1	461.0
Landruk	19.2	327.5	653.3

Table 3.3 Mean soil properties analysed before start experiment in different cropping practices at Bandipur (2000)

Cropping System	pH	OC (g/ kg)	TN (g/kg)	Av. P (mg/kg)	Exch. K (mg/kg)	CEC (meq/100g)
Wide-terraced maize- based	4.5	11.3	2.4	6.3	177.2	34.3
Young citrus orchard	5.0	19.0	2.0	10.9	228.1	41.1
Narrow-terraced maize-based system	4.6	13.0	2.3	12.7	176.1	36.1
Old citrus orchard	5.9	11.5	2.3	18.9	114.7	58.4
Mean	**5.0**	**13.7**	**2.2**	**12.2**	**174.0**	**42.5**

3.4.7 Nutrient analysis in the water samples (rainfall, leachate and runoff)

Nitrate N, dissolved phosphorus and potassium concentrations in the rain, leachate and runoff samples were determined. Nitrate N was estimated using NaOH for colour development in the colorimetric method. Phosphorus and potassium concentrations were determined using spectrophotometry and flame photometry respectively as described by Anderson *et al.* (1993).

3.4.8 Crop yields

The total number of cob-bearing and non cob-bearing maize plants was counted and 10 percent samples from both categories of plants were randomly harvested from all terraces. Biomass yield and grain yield were recorded. Millet biomass yield was sampled from five randomly selected 1 m^2 areas in each plot. The grain was separated from the straw. Grain weights and moisture content were measured. The same was carried out for barley.

The yield of ginger was recorded as rhizome fresh weight. The soybean yield was recorded by weighing the whole plant and then separating the grain from stems. There was no yield of cowpea and field bean from their strips. The subsamples of grain and stems were oven dried to estimate moisture content. Grain yields at storable moisture content and straw yield at oven dry weight were converted into kg per hectare. The adjusted moisture contents for storable grain were 12% for millet, wheat and barley, and 14% for maize. The grain yields of maize and soybean and rhizome yield of ginger from Nayatola were converted into gross return as rupees per hectare. The whole season total yields for grain and straw in Landruk were recorded in kg/ha. The stubble from all crops from both sites was recorded as straw yield in kg/ha. No winter crop yields from Nayatola or any crop yields at Bandipur were recorded.

3.5 DATA ANALYSIS

Rainfall data were analysed using the ftn90 software package to obtain total rainfall per day and kinetic energy produced during rainfall. The rainfall was subtotalled to the dates coinciding with runoff, leachate and sediment measurement. Manually recorded rainfall data were used where data from the automatic rain gauge were not available. However, manually recorded rainfall could not provide information on erosive characteristics of the rainfall. Runoff and leachate were calculated in mm and as a percentage of rainfall. The sediment and nutrient contents of the leachate, runoff and eroded sediment were converted into kg/ha. All these values were calculated for the whole season and for different periods of the season in order to investigate the dynamics of erosion and nutrient loss over time. Gardner *et al.* (2000) emphasised that nutrient concentrations vary on a seasonal and daily basis and nutrient losses in erosion peak in all the farming systems in the pre-monsoon season. The periods of the season were defined according to rainfall patterns at the different sites. The periods were early (before June 15th) and mid (after 16th June) in 2000 and early (before 15th June), mid monsoon season (16th June to 15th August) and late (after 16th August) in 2001 and 2002 for Nayatola. The periods were defined as early monsoon season (before 31st May), mid monsoon season (from 1st June to 31st July) and late (after 1st August) for Landruk in all three years. The same periods of early, mid and late, monsoon season were used for Bandipur in 2000, 2001 and 2002.

Data on all observations were summarised and analysed using different statistical packages. Effects of treatments on leachate, runoff, sediment, dissolved nutrients in runoff and leachate were compared using ANOVA, applying the general linear model in minitab PC version 13 (model of ANOVA table in appendix 3.1 a and c). The effects of treatments and plot positions on soil properties were compared using ANOVA applying the split plot technique in Genstate PC verson 6 (model of ANOVA table in appendix 3.1 b and d). Sediment nutrients and crop yields were compared using ANOVA applying general treatment structure in randomised block technique in Genstate PC version 6. Contrast between the mean of interventions and control and between the two interventions was also performed in Genstate PC version 6 (model of ANOVA table in appendix 3.1 e). Means were compared at the 95% confidence level of probability to test the effects of the treatments. Level of probability was computed and has been presented with text to confirm confidency on the effect of treatments. Information has been also presented in graphical form with error bars for indivisual treatments and vertical line indicating the value of standard error of difference across all treatments. Numerical value of standard error of difference (SED) between the treatments was also determined and information has been presented with mean data in the tables.Most of the data were also transformed to log_{10} values and analysed.

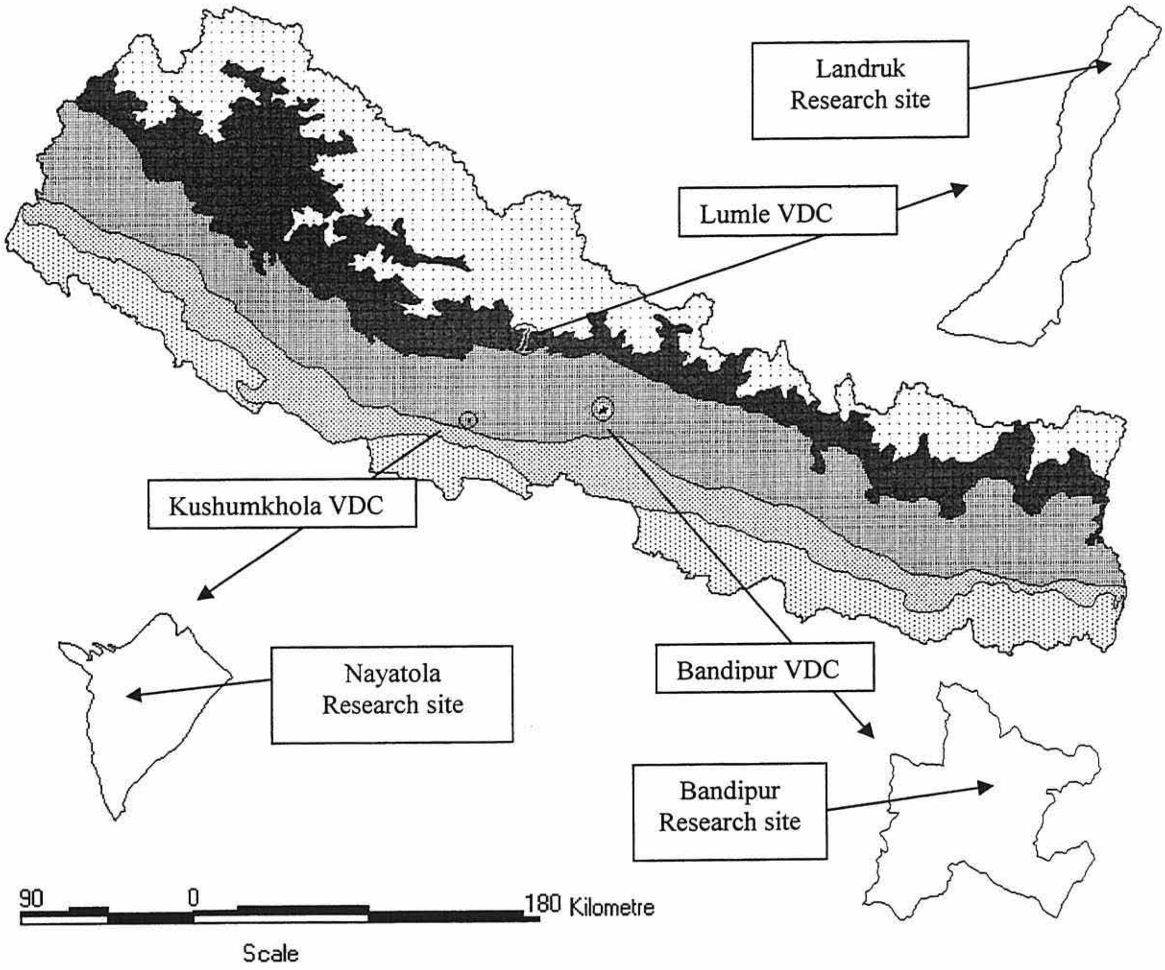


Fig. 3.1 Map of Nepal showing the research sites

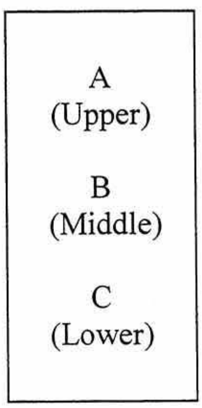


Fig. 3.2 Plot positions

Plate 3.1 Sloping land cultivation system at Nayatola.

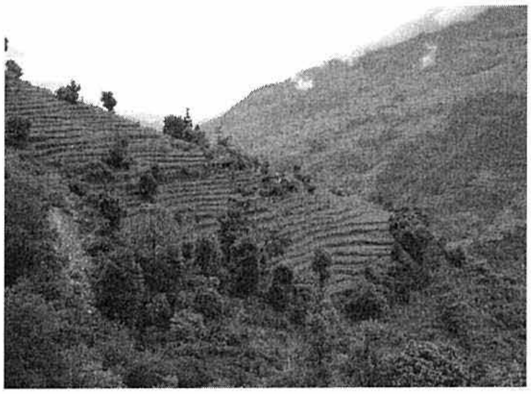


Plate 3.2 A Bench terracing system at Landruk.

Plate 3.3 Bunded experimental plots

Plate 3.4 Arangement of runoff collection drums.

Plate 3.5 A lysimeter used to collect leachate.

CHAPTER 4

INTERVENTIONS TO MINIMISE SOIL AND NUTRIENT LOSSES IN THE SLOPING TERRACE CULTIVATION SYSTEM IN LOW TO MEDIUM RAINFALL AREAS

4.1 INTRODUCTION

The sloping land cultivation is common to a few districts of Nepal, perticularly Palpa, Gulmi and Arghakhanchi in the Western Development Region. Maize is the main food crop to be grown in the sloping *bari* lands in summer. Other crops such as ginger (a cash crop) may also be grown along with maize. A few species of legume such as soybean, cowpea and rice bean are grown in a mixed cropping system. Wheat, barley, mustard and field peas are winter crops grown after the harvest of summer crops. Summer crops receive sufficient rain to produce good yield at harvest but winter crops receive little or no rain and are dependent on residual soil moisture. In some years these crops produce no yield.

These cultivated areas receive low total annual rainfall compared with the eastern middle hills. However, some torrential rainfall can cause significant runoff and soil loss. Sloping lands and existing crop cultivation practices are thought to contribute to an increase in soil loss.

The principal components of environmentally sustainable farming systems are the reduction of soil erosion, use of legumes and cover crops, successful introduction of agroforestry systems, and effective use of organic wastes (Singh and Singh, 1995). Use of mulch is not widespread in these areas. However, ginger grown under a mulch of plant material is an exception. Ginger is an important cash crop for the Magar caste of hill farmers in the Palpa district (Bergor, 1978). The mulching practice is limited to a very small area of cultivation. Light mulch can reduce runoff and erosion on a 50 % slope in the semiarid region of Santiago Island (Smolikowski *et al.*, 1998). The mulch not only reduces runoff and erosion but also improves the soil's physical structure. By addition of organic matter soil porosity is improved. This increases hydraulic conductivity which in turn increases water infiltration and improves soil biological processes (Mando, 1998). Application of mulch to the soil surface protects it from rain drop impact and helps to prevent its detachment and movement down the slope (Montoro *et al.*, 2000).

There are a number of technologies to control soil erosion and loss of nutrients. Some soil conservation technologies control erosion but cannot fulfil the immediate demands of the farmers. Alley cropping controls erosion but cannot maintain soil fertility and high crop yields (Ongprasert *et al.*, 1996). Farmers do not easily agree to decrease the production of maize unless convinced that the result will mean a better income. The sustainable management of land resources must lead to increased profit especially attractive to farmers in the short-term (Richard and Josenestor, 2002).

Strip cropping reduces soil loss through runoff in steeply sloping cultivated lands compared with control plots. Strip cropping of sweet corn and cowpea resulted in the lowest soil loss in Thailand (Thapathip *et al.*, 1989). Row crops are sensitive to erosion but they can be cultivated in alternation with other crops resistant to erosion for minimising soil loss from runoff in steeply sloping cultivated lands (Davies *et al.*, 1993). Maize is grown in rows and it is sensitive to erosion. It can be grown with alternate strips of other crops which are tolerant to erosion. Cowpea and soybean are the dominant legumes to be grown with maize during the summer (mixed cropping) in the mid and high hills (Acharya, 1999). Most of the legume crops are resistant to soil erosion and are known as cover crops. These provide a comprehensive vegetative cover, reducing sediment loss from 20 t/ha to 0.02 t/ha in the *bari* lands in the mid to high hills with the same rainfall during the pre-monsoon period (Carver and Schreier, 1995).

Erosion control measures should involve engineering (e.g. check dams, contour dikes and terrace construction,) biological techniques (e.g. crop mulching, use of cover crops, alley cropping and strip cropping) and soil water conservation based tillage technologies (e.g. reduced tillage, no tillage and deep tillage). They should balance ecological, economic and social benefits (Aimin *et al.*, 2002). Nayatola has been selected as a site to represent mid-altitude land receiving moderate rainfall and as having large steep terraces with maize as the main crop (Mawdesley *et al.*, 1998).

The objectives of this research are to introduce strip cropping in sloping *bari* lands, to evaluate the rôle of strip cropping in the improvement of soil fertility, to minimise soil and nutrient loss, and to increase farmers' income by promoting locally adoptable crops and cultivation practices into strip cropping on sloping terraced farmlands.

4.2 MATERIALS AND METHODS

Experiments were established in five farmers' fields. One farmer's field was a block assigned a complete set of treatments. The treatments were: strip cropping with maize and ginger [Intervention 1] and strip cropping with maize and legumes such as cowpea (in the first year), soybean (in the second year) and bean (in the third year) [Intervention 2], and a control treatment (cultivation of only maize with the farmers' practice). Thus, there were a total of 15 experimental plots into 5 blocks and each block has 3 complete treatments.

The intervention treatments were randomly assigned to plots within each of the blocks. Previously established plots were used for the control treatment. Each experimental plot was 100 m^2 (5m x 20 m downslope). Each plot contained a single large outward sloping terrace. Fields were ploughed twice before planting crops using a bullock-drawn wooden plough. FYM was applied to all blocks at a rate of 10 to 25 t/ha. The amount of manure applied was the same for all plots within a block but differed from one block to another due to differences in FYM availability between farms. The amount of FYM applied was not recorded in the first year. It was recorded in the second year (and converted into kg/ha). Its moisture and nutrient contents (NPK) were analysed in the third year (Table 4.1). Maize and ginger were planted in strips in one plot and maize and legumes in the second plot. The width of the strip was 2 m for ginger and legume and 3 m for maize. Maize alone was planted in the third plot as a control (without strips as in the farmers' practice). Generally maize is mixed with legumes in the farmers' practice, the type of legume varying from farmer to farmer. All plots in a block were planted with crops on the same day and planting in all blocks was completed in the first and second weeks of June in the first year. Cowpea was the legume crop planted with maize in strips in the second intervention. In the second year all crops were planted using the same method but planting in all blocks was completed in the third week of April to the first week of May. However, soybean was planted instead of cowpea in the second intervention. In the third year planting in the experimental plots was completed in the last week of May following the same procedure as in previous years. The field bean was the legume crop used in the second intervention of the third year. Data were collected on rainfall, leachate, runoff, eroded sediment and loss of nutrients through runoff and leaching during the rainy season. The crop yields were also recorded and converted into cash income. The cultivation cost was assumed to be similar in all treatments and the cost of the mulching material has been ignored. The seed price was then deducted from the total income of each respective treatment in order to determine net income from the treatment as rupees/ha (Rs/ha). The incomes from intervention and control plots were compared on a Rs/ha basis. Plant residues (straw yields) were also compared on a kg/ha basis. Residues from ginger were not included in the total straw yields during 2000 and 2001 but were included for 2002. In addition samples of FYM used in the experimental plots, crop residues and yields were analysed for NPK content. The total nutrient budget of a season was calculated for the year 2002.

All data were analysed statistically using ANOVA in Minitab PC version 13 and Genstat 6. Means were compared at 95% confidence levels of probability.

Table 4.1 Amount of FYM with its moisture content and NPK content applied in experimental plots at Nayatola.

Block	FYM 2001	FYM 2002				
	(t/ha)	(t/ha)	Moisture content (g/kg)	N content (g/kg)	P content (g/kg)	K content (g/kg)
1	37.5	12.5	743.2	19.8	4.3	17.3
2	31.3	31.3	711.9	20.2	5.2	22.4
3	37.5	15.6	708.9	20.4	3.3	21.0
4	13.6	10.8	709.7	19.9	3.6	24.9
5	11.3	9.4	736.4	20.6	4.2	22.8
Mean	**26.2**	**15.9**	**722.0**	**20.1**	**4.1**	**21.7**

4.3 RESULTS

4.3.1 Rainfall and its erosivity

Total rainfall and its distribution during the monsoon periods varied from year to year (Fig. 4.1). The erosive index of rainfall was calculated using the maximum 15 minute rain intensity (EI 15) and the empirical equation (Zanchi and Torri, 1980 quoted by Gardner *et al.*, 2000) in the software package Ftn90.

In 2000 there was a total of 1386 mm rainfall during the monsoon period, producing a kinetic energy (KE) of 11569.5 MJ mm/ha/h with a maximum KE of 3142.4 MJ mm/ha/h in a single rainfall event. Rainfall was 473 mm in the early monsoon period (before 15th June) and 912 mm in the mid monsoon period (from 16th June to 15th August), producing KE of 5778.3 and 5795.1 MJ mm/ha/h (maximum KE of 3142.4 and 2985.0 MJ mm/ha/h in a single rainfall event) respectively.

In 2001 there was a total of 1124 mm rainfall during the whole monsoon period. The KE produced by rain was 9968.7 MJ mm/ha/h with a maximum of 2767.2 MJ mm/ha/h in a single rainfall event. The rainfall was 190, 431 and 503 mm in the early-, mid- and late-monsoon periods respectively. KE produced by rain in the early-, mid- and late-monsoon periods was 1778.9, 2372.5 and 5817.3 MJ mm/ha/h respectively (maximum KE in a single rainfall event was 407.2, 431.1 and 2767.2 MJ mm/ha/h respectively).

In 2002 the total rainfall during the whole season was 869.6 mm producing a total of 11283.7 MJ kinetic energy with the maximum kinetic energy of 2639.9 MJ mm/ha/h on 20th August. The distribution of rainfall was 239.8 mm in the early-monsoon, 216.4 mm in the mid-monsoon and 413.4 mm in the late-monsoon. The rainfall produced KE of 4071.4, 930.2 and 6282.2 MJ mm/ha/h respectively with a maximum of 1428.3 MJ mm/ha/h on May 14th, 372.0 MJ mm/ha/h on 12th August and 2639.9 MJ mm/ha/h on 20th August respectively.

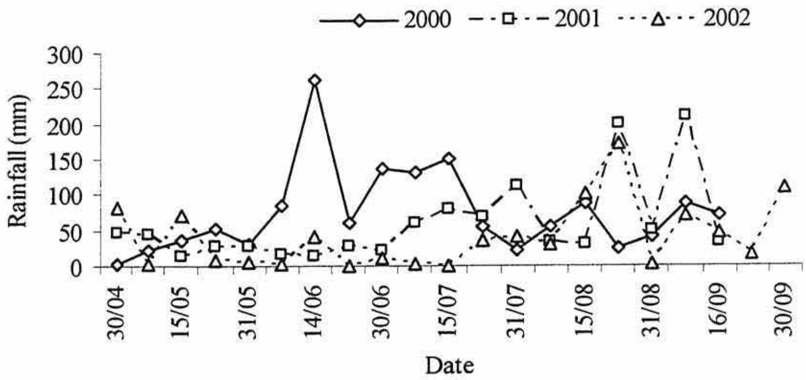


Fig. 4.1 Rainfall at Nayatola (2000-2002)

4.3.2 Runoff

Interventions did not significantly affect the amount of runoff in any year of experimentation ($P \geq 0.14$). However, runoff from intervention plots was low compared with the runoff from the control in each year.

In 2000 runoff from treatment plots was not significantly different ($P = 0.49$) even when data were transformed into $\log_{10}$ values. The percentage runoff was higher after the early monsoon (Fig. 4.2 a). Strip cropping with maize and ginger produced less runoff compared with the control plot over the whole season (Fig. 4.3 a). Strip cropping did not affect runoff during the early-monsoon period and reduced runoff during the late-monsoon period compared with the control. Maize and cowpea strips showed slightly higher runoff during the early-monsoon and slightly reduced runoff during the mid-monsoon period.

In 2001 the highest percentage runoff was in the mid season and the lowest was in the late season (Fig. 4.2 b). The effect of intervention on total runoff for the whole season was significant ($P = 0.03$) [Fig. 4.3 b]. Individually the effect was not significant for early-, mid- and late-monsoon periods when data were transformed into $\log_{10}$ values ($p = 0.05$). The maize and ginger strips reduced runoff (12.2 mm compared with 22.5 mm in the control plot) over the whole season and reduced runoff in the early-, mid- and late-monsoon periods. No reduction in runoff was seen in the maize and soybean strip cropping.

In 2002 the highest percentage runoff was from the control plot (8.2 %) in the early-monsoon period (Fig.4.2 c). The effect of intervention was significant at a low level ($P = 0.14$) and maize and ginger strip cropping reduced runoff to 6.4 mm (compared with 27.0 mm in the control plot) [Fig. 4.3 c]. Maize and bean strip cropping also produced less runoff (16.3 mm compared with the control plot). In the early-monsoon period both interventions produced less runoff than the control plot. In the mid- and late- monsoon periods there was less runoff and differences between treatments were also less ($P = 0.21$ to 0.49).

Runoff was higher in the early monsoon showing a trend of decreasing runoff from the early to late periods. When contrast analysis was performed, neither the mean of intervention treatments showed a significant difference with control ($P = 0.35$) nor did the two intervention treatment means significantly differ with each other ($P = 0.39$) in 2000. The differences between the mean of interventions and control, and between interventions were increased ($P =$ 0.21 and $P = 0.11$ respectively) in 2001. The difference increased further between intervention and control ($P = 0.08$) but decreased between the two interventions ($P = 0.31$) in 2002. The trend in differences between intervention and control indicates that there is a positive effect of strip cropping in runoff control. The differences between interventions were not consistent enough to determine which treatment was better able to minimise runoff. The growth of legume crops in the strip cropping plot was not constant in all years. The soybean grew satisfactorily in 2001. Results confirmed that maize and ginger strips were better than maize and soybean in minimising runoff. The poor growth of legumes in different years contributed to less of a difference between the intervention and control plots.

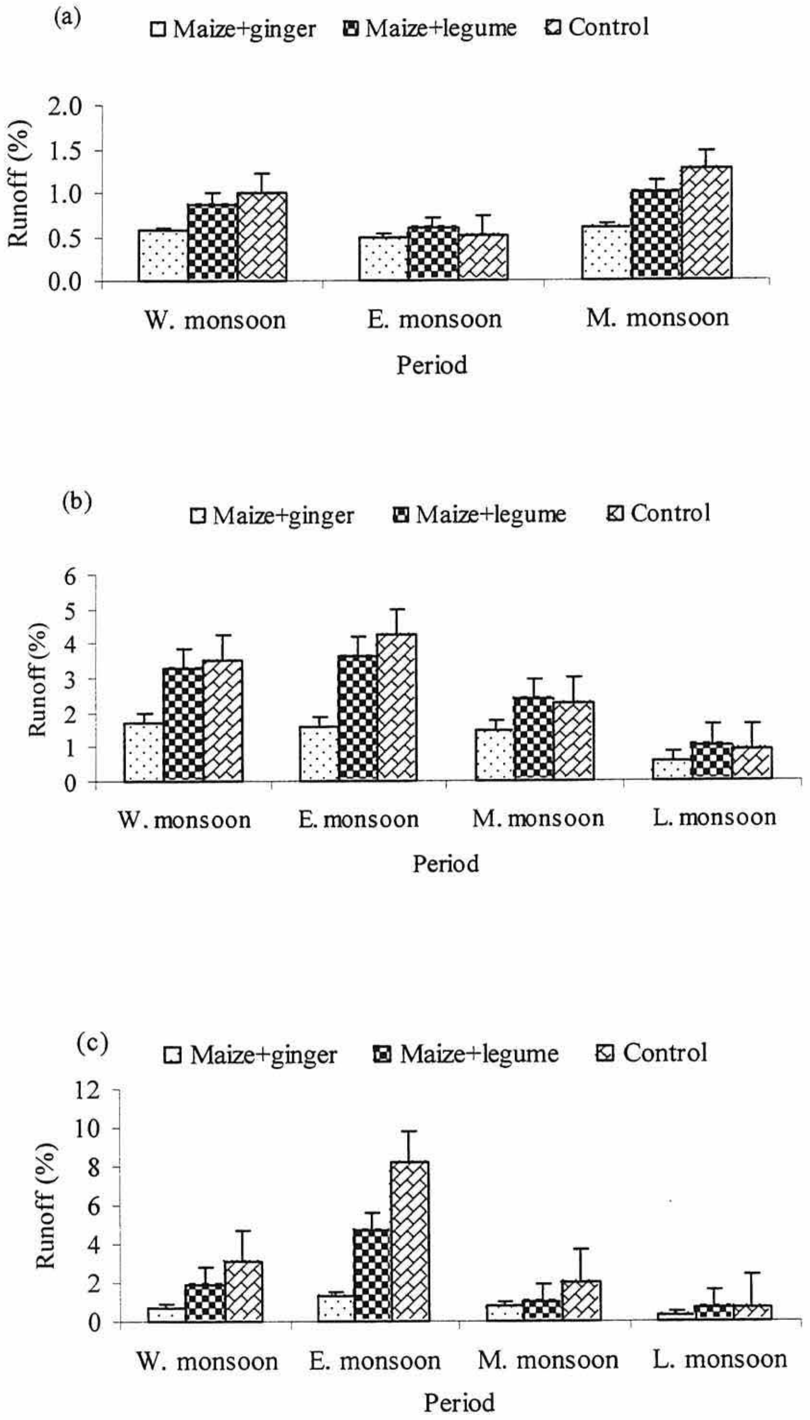


Fig.4.2 Runoff (percentage of rainfall) during (a) 2000, (b) 2001 and (c) 2002 at Nayatola.

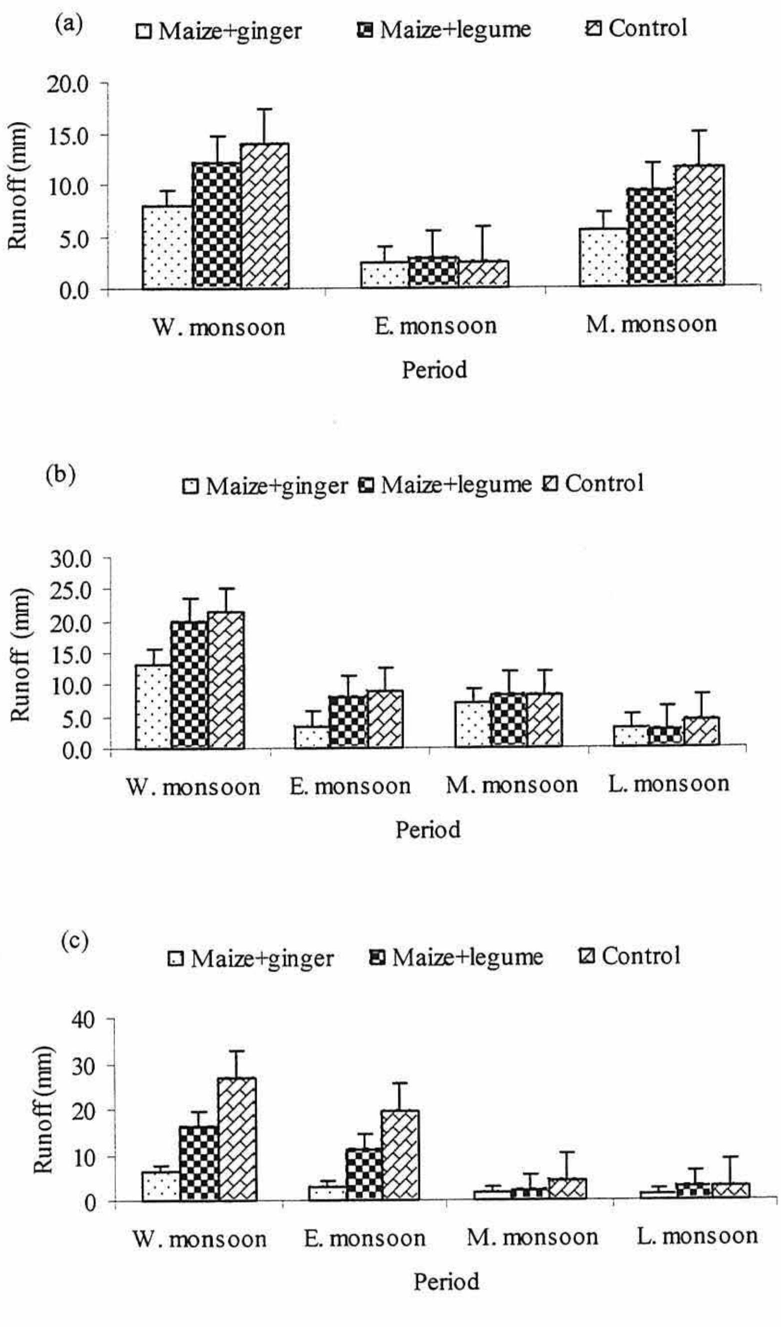


Fig. 4.3 Runoff (mm) during (a) 2000, (b) 2001 and (c) 2002 at Nayatola.

4.3.3 Eroded sediment

The sediment loss with runoff was not significantly different between the intervention and control treatment in any periods over the three years ($P = 0.30$, $P = 0.13$ and $P = 0.20$ in 2000, 2001 and 2002 respectively).

In 2000 maize and ginger cropping in strips reduced total sediment runoff as well as sediment runoff in early-monsoon and mid-monsoon periods compared with the control. However, maize and cowpea strips produced a negative effect by increasing sediment loss compared with the control (Fig. 4.4 a). Poor cowpea growth and the fact that farmers dug the fields thoroughly during inter-culture operations resulted in higher sediment loss. The difference between the mean of the interventions and the control was low ($P = 0.88$) and the difference between the means of interventions was high ($P = 0.14$). The mean sediment loss from the maize and ginger intervention is lower (57.8 kg/ha) than that from the control plot (144.3 kg/ha). The higher sediment yield from maize and cowpea strip cropping resulted in less of a difference between the sediment from intervention and control plots.

In 2001 both interventions (maize/ginger and maize/soybean) reduced total sediment loss as well as losses of sediment in the early-monsoon, mid-monsoon and late-monsoon periods compared with the control. However, the sediment loss from maize and soybean strips was higher than that from the control plot in the mid-monsoon period (Fig. 4.4 b). The difference between the sediment loss from the intervention plots and the control plot was significant ($P =0.08$) and the difference between interventions was insignificant ($P = 0.30$). This shows the effectiveness of the interventions in controlling soil runoff loss.

In 2002 the difference in sediment loss between the interventions and the control plot was insignificant ($P = 0.20$). Soil loss was 280.7 kg/ha in maize and ginger strip cropping, 865 kg/ha in maize and bean strip cropping, and 1756 kg/ha in the control plot. The trend in soil loss in the intervention plots and the control plot in the early-monsoon was similar to the trend of total soil loss over the whole season. The highest soil loss, irrespective of treatment, occurs in the early-monsoon. Soil loss in the early-monsoon was 269.5, 843.0 and 1730.6 kg/ha in maize and ginger strip cropping, maize and bean strip cropping and the control respectively.

An insignificant amount of soil was lost in the mid- and late- monsoon. However, the trend amongst the treatments was the same as that in the early monsoon (Fig. 4.4 c). The difference in the sediment loss from the mean of interventions and the control was the same as that in 2001 ($P = 0.11$) and the difference between interventions was further reduced ($P = 0.46$).

In the control one rainfall event of 61 mm caused soil loss of 171 kg/ha. This occurred in the early-monsoon in 2000 but maize and ginger strip cropping reduced soil loss below 10 kg/ha in the same rainfall event (Fig. 4.5 a). In 2001 soil loss was higher with an event of 11 mm rainfall. After this event maize and ginger strip cropping reduced soil loss many times compared with the control (Fig. 4.5 b). In 2002 there was only one event (57 mm rainfall) in which a 1664 kg/ha soil was lost from the control compared with only 247 kg/ha from the maize and ginger and 768 kg/ha from the maize and legume strip cropping. After this, soil loss was negligible in all plots even with higher rainfall (Fig. 4.5 c).

There were less soil loss events in 2000 and 2002. Regression analysis did not establish the trend of soil loss with the rainfall kinetic energy. However, KE and soil loss regression was plotted from the soil loss in 2001 (Fig. 4.14). Relationship is linear but insignificant. Most of soil losses were found below 1000 MJ mm/ha/h. Maize and ginger and maize and legume strip cropping showed decreasing soil loss and control showed increasing soil loss trend with increasing KE. Rainfall of high KE might have occurred at any periods of monsoon but soil remains sensitive at early and tolerant at late monsoon period depending upon the stage of ground cover and interculture operation to the crops.

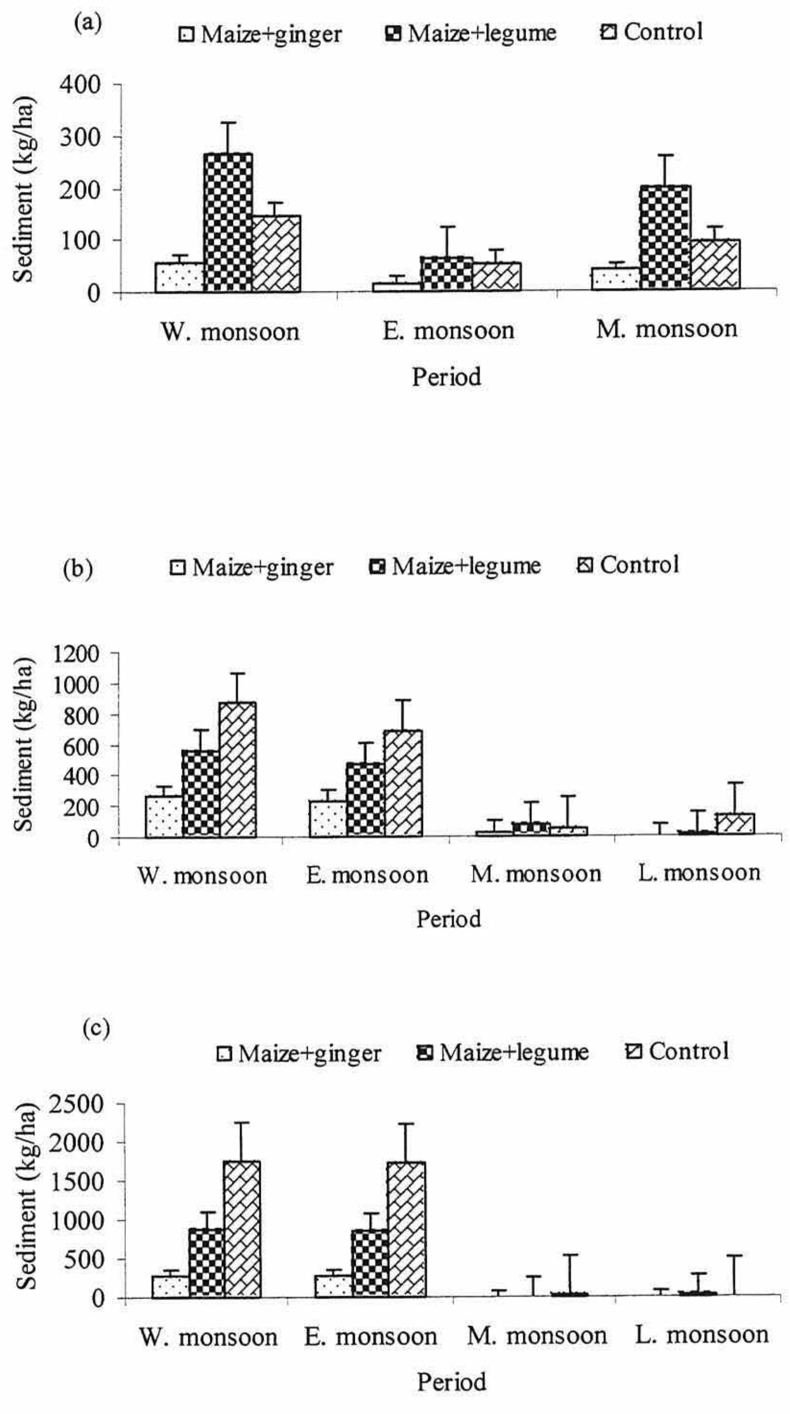


Fig. 4.4 Eroded sediment during (a) 2000, (b) 2001 and (c) 2002 at Nayatola.

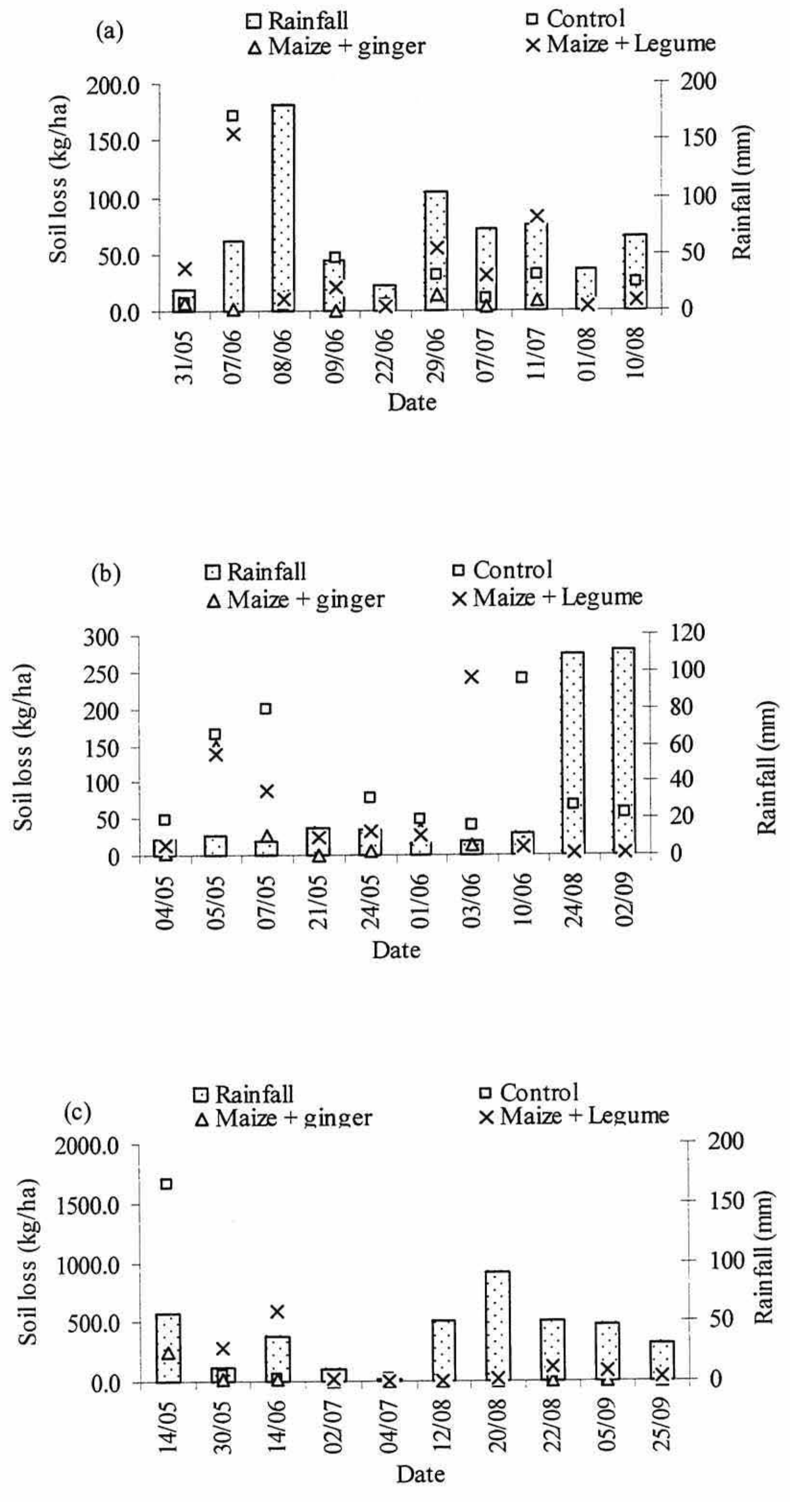


Fig. 4.5 Soil loss events during (a) 2000, (b) 2001 and (c) 2002 at Nayatola.

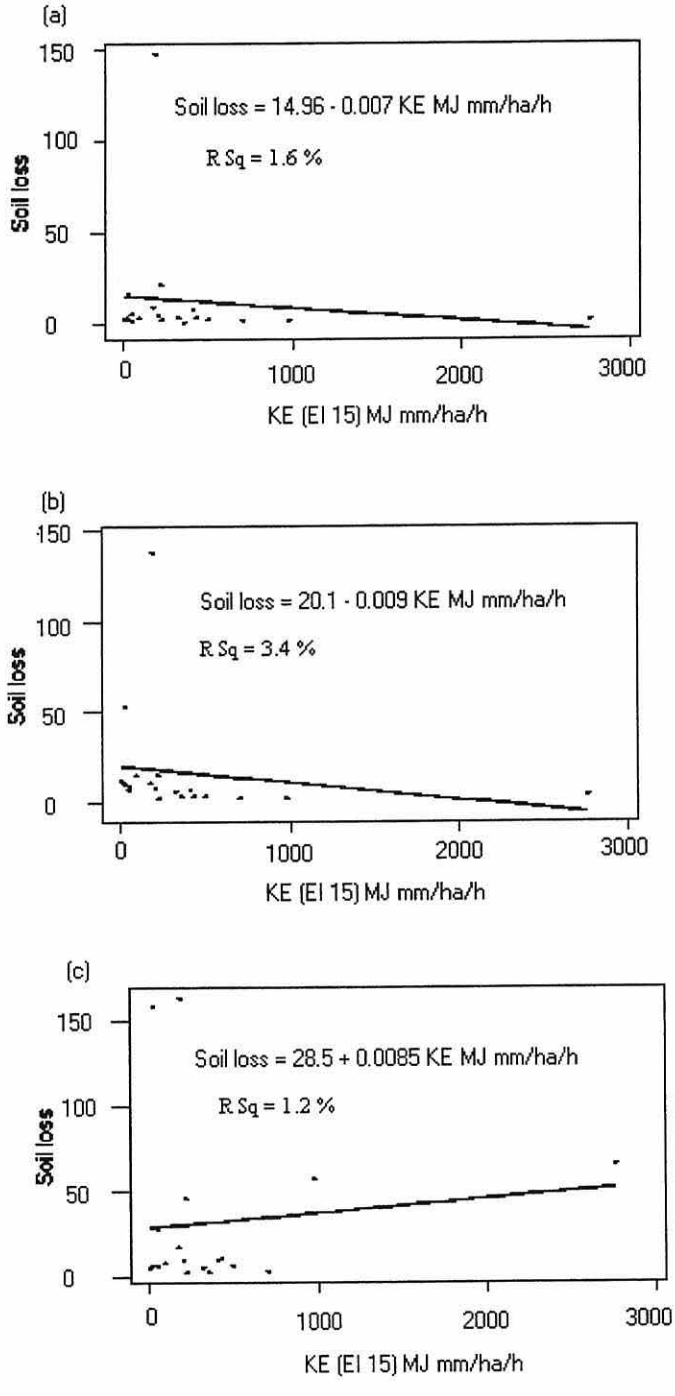


Fig. 4.6 Regression plot of KE (MJ mm/ha/h) and soil loss (kg/ha) in (a) maize and ginger strip cropping, (b) maize and legume strip cropping, (c) control plot (2001) at Nayatola.

4.3.4 Soluble nutrients in runoff

Laboratory analysis of the runoff samples showed that the dissolved nutrients in runoff, N (nitrate), P and K were lost less through runoff than with leachate because there is low runoff and high percolation. The losses of these nutrients did not differ significantly ($P \geq 0.14$) when intervention plots were compared with the control plot. The amount of N and P lost through runoff in a whole season was less than 1 kg/ha. The amount of K lost was under 2 kg/ha (Figs. 4.7). Results show that water flow from the surface contains low concentrations of nutrients.

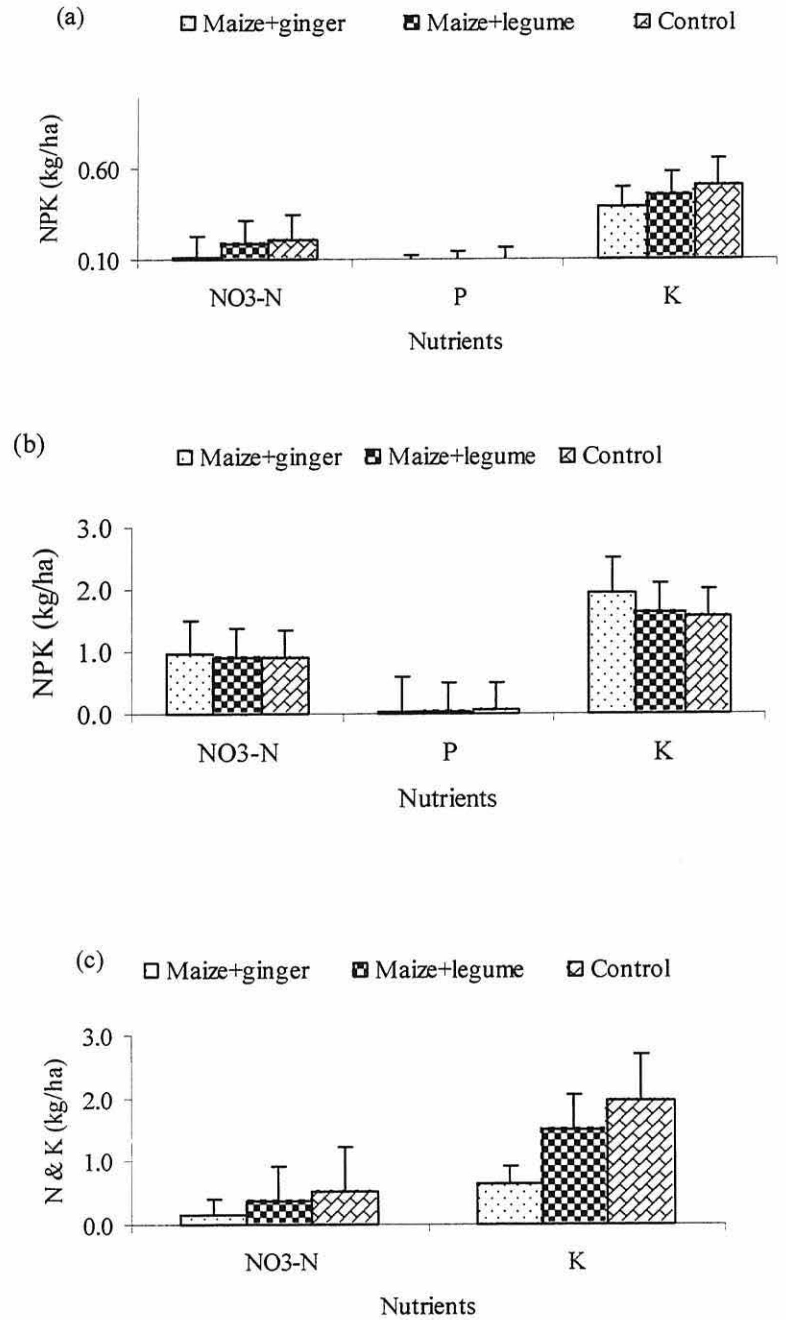


Fig. 4.7 Nutrient loss in runoff during (a) 2000, (b) 2001 and (c) 2002 at Nayatola.

4.3.5 Nutrient content in eroded sediment

The eroded sediments from all 3 years were analysed for organic carbon, total nitrogen, available P and exchangeable K. In statistical analysis nutrient contents of eroded sediments in the treatment plots were not significantly different in any of the three years (Table 4.2).

In 2000 the lowest organic carbon content (33.8 g/kg) was found in the eroded sediment collected from the control plot and the highest was found in the eroded sediment collected from the maize and legume strip cropping plot (47.6 g/kg). The intervention and control plots were not significantly different in carbon content (P = 0.78) and there was no significant difference between the means of the two interventions (P = 0.19). The lowest concentration of total N in eroded sediment was found in maize and ginger strip cropping (0.72 g/kg) and the highest was found in the control plot (0.80 g/kg). No significant difference between intervention and control or between the two interventions was observed (P = 0.90 and P = 0.13 respectively) for total N content in the eroded sediment. P content in the sediment removed from the maize and ginger strip cropping plot was higher (163 mg/kg) than that from the control plot (117 mg/kg). However, P content was lower in that from maize and legume strip cropping (62.1 mg/kg). Exchangeable K was higher in the eroded sediment of maize and ginger strip cropping (222.1 mg/kg) compared with that of the control plot (181.2 mg/kg). The eroded sediment from the maize and legume strip cropping had the lowest K content (177.1 mg/kg).

In 2001 organic carbon content was highest in the eroded sediment from the maize and ginger strip cropping plot (56.7 g/kg), that from control being 55.3 g/kg and from maize and soybean strip cropping being 53.6 g/kg. There was no significant difference between the mean of interventions and control or between the two interventions for organic carbon content in the eroded sediment ($P \geq 0.70$). The sediment collected from the control plot had the highest total N content (1.4 g/kg) and the sediment collected from maize and soybean strip cropping had the lowest total N content (1.1 g/kg). The differences between the mean of the two interventions and the control as well as between the two interventions were not significant (P = 0.46 and P = 0.56 respectively). Available P was highest in the eroded sediment from the control plot (95.4.0 mg/kg). P content in the eroded sediment from the maize and ginger and maize and legume strip cropping plots were 73.4 and 61.1 mg/kg respectively. The difference in P content between the mean of the interventions and the control was significant ($P = 0.04$) but was insignificant between the two interventions ($P = 0.38$). Exchangeable K was highest in the eroded sediment from maize and ginger strip cropping (469 mg/kg) and it was the lowest in the eroded sediment from maize and soybean strip cropping (433 mg/kg). Both the differences between the mean of interventions and control as well as between the two interventions were insignificant ($P = 0.36$ and $P = 0.78$ respectively).

In 2002 organic carbon content was highest in the sediment collected from maize and ginger strip cropping (16.65 g/kg) and was lowest in the sediment collected from the control plot (13.0 g/kg). Total N content was highest in the sediment collected from the control plot (2.17 g/kg) and lowest in the sediment collected from the maize and legume strip cropping plot (1.9 g/kg). Available P was higher in the control plot (42.1 mg/kg) than in both interventions (29.7 and 37.3 mg/kg). Exchangeable K was highest in the control plot (264 mg/kg) and lowest in maize and bean strip cropping (216 mg/kg). The difference between the mean of interventions and the control as well as between the two interventions was insignificant ($P \geq 0.05$) for organic carbon, total N, available P and K content in the eroded sediments.

Table 4.2 Nutrient content of eroded sediments from different treatments (2000-2002).					
Year	Treatment	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	Exch. K (mg/kg)
2000	Maize/ginger strip cropping	43.6	0.72	162.60	222.10
	Maize/legume strip cropping	47.6	0.73	62.10	177.10
	Control (farmers' practice)	33.8	0.80	116.70	181.20
	Mean	**41.6**	**0.75**	**114.0**	**193.4**
	SED	**04.81**	**0.044**	**27.9**	*
2001	Maize/ginger strip cropping	56.7	1.37	73.4	469.00
	Maize/legume strip cropping	53.6	1.14	61.1	433.20
	Control (farmers' practice)	55.3	1.40	95.4	442.10
	Mean	**55.2**	**1.28**	**76.6**	**448.1**
	SED	**7.71**	**0.27**	**13.17**	**35.0**
2002	Maize/ginger strip cropping	16.6	2.15	37.30	232.4
	Maize/legume strip cropping	15.2	1.88	29.70	216.00
	Control (farmers' practice)	13.0	2.17	42.10	264.30
	Mean	**15.0**	**2.1**	**36.3**	**238.0**
	SED	**2.45**	**0.19**	**6.91**	**125.7**

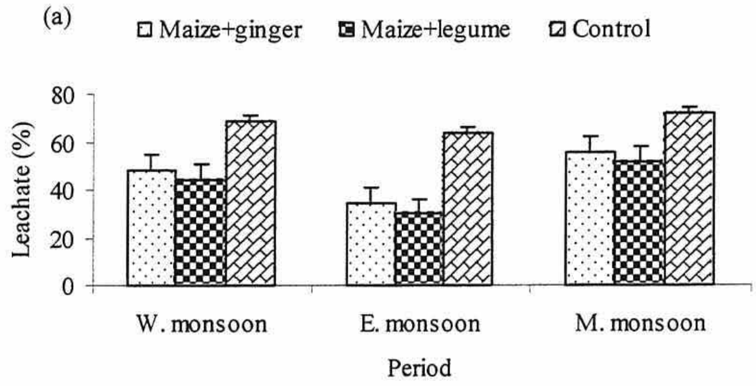
* Not analysed

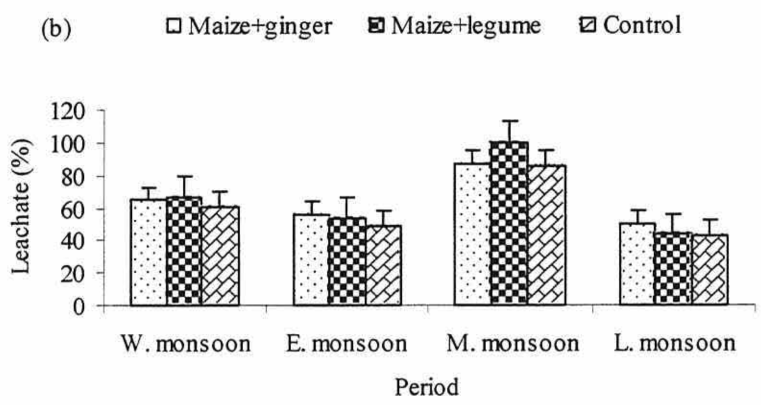
4.3.6 Leachate

Leachate was measured in the rainy season over the 3 years from 2000 to 2002. Leachate was not found to be significantly different in intervention and control plots. In 2000 leachate from the maize and ginger strip cropping plot was 671.4 mm (48.5 % of the total rainfall) whereas leachate from the control plot was 768.0 mm (68.8 % of the rainfall). Leachate from the maize and cowpea strip cropping plot was 665 mm (44.1 % of the rainfall) [Figs. 4.8 (a) and 4.9 (a)]. In the early-monsoon period the leachate was slightly higher from maize and ginger strips than from the control and was slightly lower in maize and cowpea strips than from the control plot. However, leachate from the control plot was higher than that from intervention plots in the mid-monsoon period. Irrespective of treatment, a higher percentage of rainwater percolated in the mid-monsoon period than in the early-monsoon period. The difference between intervention and control was greater (P = 0.25) than the difference between the two interventions (P = 0.99).

In 2001 the leachate was lowest in the control plot (681.5 mm and 60.7 % of the total rainfall). It was 728.9 mm in maize and ginger strips (64.9 % of the total rainfall), and it was 753.8 mm in maize and soybean strips (67.1 % of the total rainfall) [Figs. 4.8 (b) and 4.9 (b)]. The leaching trend in the different treatments was similar in early-, mid- and late-monsoon periods. However, a higher proportion of rainfall percolated in the mid-monsoon than in the late-monsoon in all treatments. The difference between the intervention and control and between the two interventions was insignificant (P = 0.70 and P = 0.89 respectively).

In 2002 total leachate was highest in maize and ginger strip cropping (328 mm) and the lowest in maize and bean strip cropping (287 mm). The leachate was 323 mm in the control plot. The water infiltration trend in all treatments in the early and late monsoon periods was the same as that for total leachates except that in the mid-monsoon it was higher in the control plot (96.5 mm) than in the intervention plots (75.1-91.3 mm). The lowest leachate was observed in the maize and legume strip cropping plot (75.1 mm). The leachate was higher in the mid monsoon than in the early- and late-monsoons in all treatments (Figs. 4.8 (c) and 4.9 (c)). However, total rainfall was higher in the late-monsoon. The percentage of rainfall in leachate varied. It was 33 % in maize and bean strip cropping and 37 % in both the maize and ginger strip cropping and control plot. The difference between the mean of the two interventions and the control as well as between the two interventions was insignificant (P = 0.76 and P = 0.49 respectively).





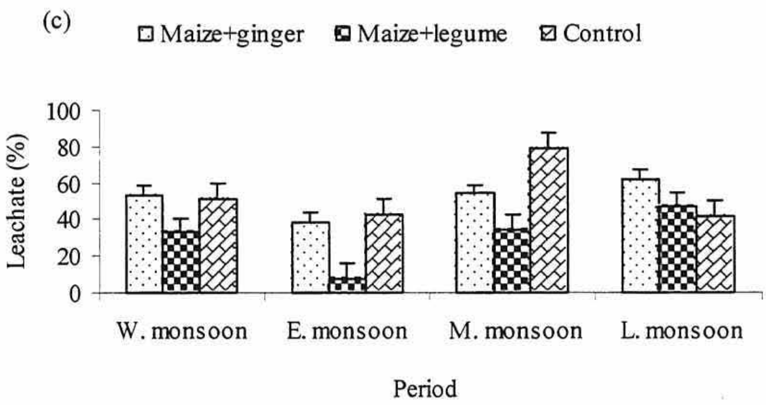


Fig. 4.8 Leachate (percentage of rainfall) during (a) 2000, (b) 2001 and (c) 2002 at Nayatola.

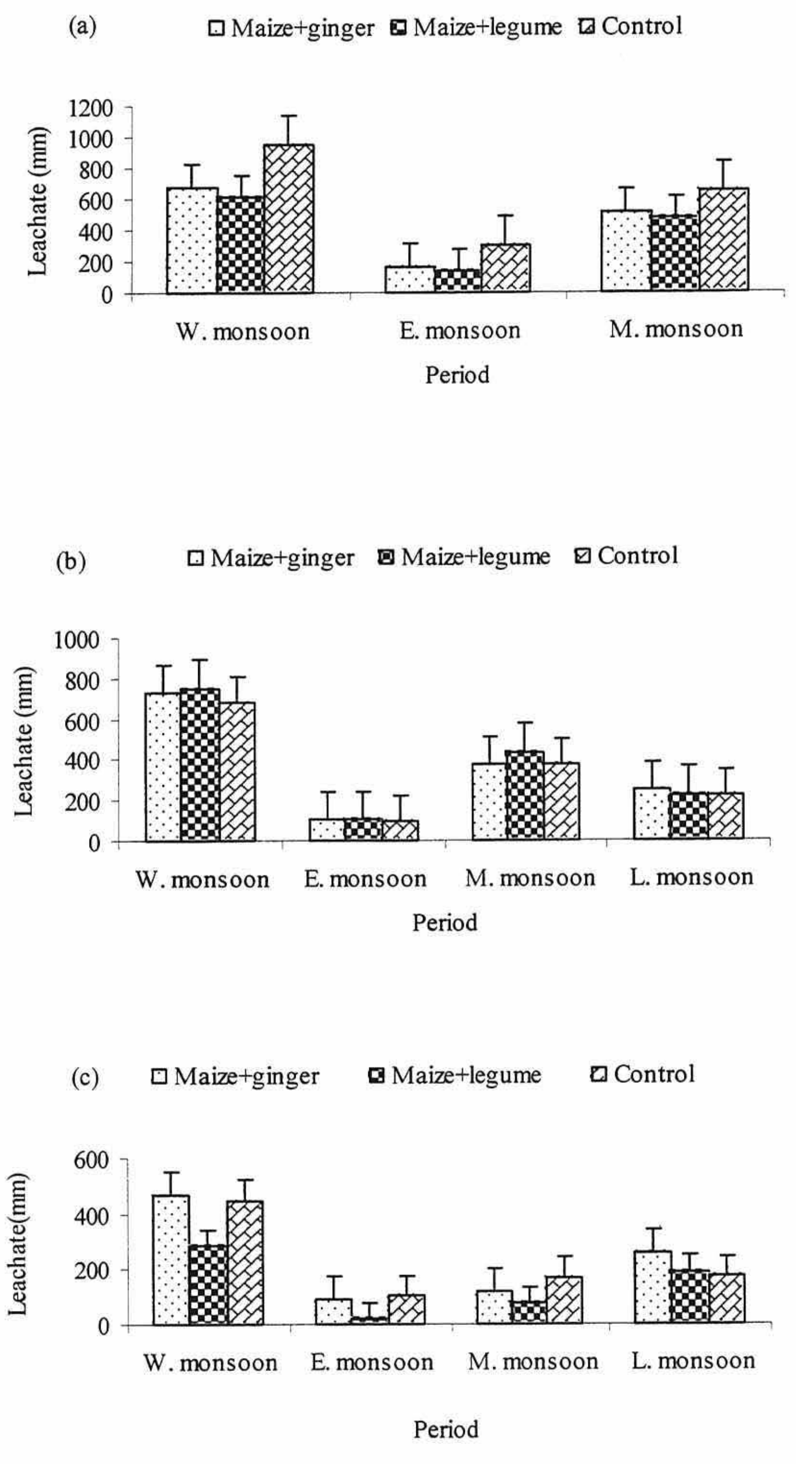


Fig. 4.9 Leachate amount (mm) during (a) 2000, (b) 2001 and (c) 2002 at Nayatola.

4.3.7 Nutrient leaching

Soluble nutrients, leached along with percolation water, were not affected significantly by interventions in any of the experimentation years. Leachate samples were analysed for NO_3-N, P and K content. A considerable amount of N and K were found to be lost along with percolation water. A negligible amount of P was leached.

In 2000 the amount of nitrate nitrogen leached from the maize and cowpea strip cropping was higher (64.5 kg/ha) than the amount from the control (60.3 kg/ha). Less nitrate nitrogen was leached from maize and ginger strip cropping (52.6 kg/ha) [Fig.4.10 a]. The leaching of nitrate N in the early-monsoon period was 39.1- 41.5 kg/ha in the interventions and 37.3 kg/ha in the control. The leaching of nitrate N in the mid-monsoon period was greater from maize and cowpea strip cropping than from maize and ginger strip cropping. Its leaching was higher from the control plot than from maize and ginger strip cropping. However, the leaching of NO_3-N was higher in the early-monsoon period in all treatments than in the mid-monsoon period. Leaching of phosphorus was lowest in maize and ginger strip cropping (1.02 kg/ha) and highest in maize and cowpea strip cropping (2 kg/ha) [Fig. 4.10 b]. The loss of P was also lowest from maize and ginger strip cropping and highest from the maize and cowpea strip cropping in the early-monsoon period but in the mid-monsoon period P was leached more from the control plot than from intervention plots. Potassium leached slightly less from the control plot (22.5 kg/ha) over the whole monsoon season compared with the intervention plots (23 - 25.1 kg/ha). Maize and ginger strip cropping leached less potassium than maize and cowpea strip cropping (Fig. 4.10 c). The control plot lost less K (4.3 kg/ha) than intervention plots (ranging from 7.5 to 7.9 kg/ha) in the early-monsoon period. Leaching of K from the control plot was higher (18.2 kg/ha) than from intervention plots (16.6 -17.3 kg/ha) in the mid-monsoon period. Leaching of K was lower in the early-monsoon period than in the mid-monsoon period in all treatments. The difference in NO_3-N leaching between the mean of interventions and control was lower (P = 0.85) than the difference between the two interventions (P = 0.29). The P leaching trend was found to be similar to the N leaching trend when comparing treatments. The difference between the mean of interventions and control and between the two interventions for K leaching was very low (P = 0.85 and p = 0.83 respectively).

In 2001 NO_3-N was leached the least from the control plot (62.1 kg/ha) compared with the intervention plots (64.2-83.6 kg/ha). Maize and ginger strip cropping leached less NO_3-N than maize and soybean strip cropping (Fig. 4.11 a). Less N was leached from intervention plots than from the control plot in the early-monsoon period. Leaching of N was higher from maize and soybean strip cropping than from the control in the mid- and late-monsoon periods. Leaching of P from the control plot was higher (0.3 kg/ha) than from intervention plots (0.10 - 0.15 kg/ha) in total over the whole season. It was higher in the early-monsoon period than in the mid- and late-monsoon periods (Fig 4.11 b). Potassium leached less from the control plot (21.7 kg/ha) than from intervention plots (26.6 - 29.5 kg/ha) over the whole season. Maize and ginger strip cropping leached less than maize and soybean strip cropping. This K leaching trend was observed in all treatments in all periods of the monsoon except in the late period when leaching of K was higher from maize and ginger strip cropping than from maize and soybean strip cropping (Fig. 4.11 c). The difference between the mean of intervention plots and the control as well as between the two interventions for NO_3-N, P and K leaching was insignificant ($P \geq 0.05$).

In 2002 nutrients such as NO_3-N and K were analysed from leachate samples. None of the nutrients were significantly affected (P = 0.05) by the treatments. The loss of total NO_3-N through leachate was highest in maize and ginger strip cropping (53 kg/ha), followed by 35 kg/ha in the control. The lowest loss was observed in the maize and bean strip cropping plot (22.0 kg/ha). The trend in loss of NO_3-N in the different treatments was similar in all monsoon periods (Fig. 4.12 a). N loss through leaching was highest in the late monsoon period. Total K loss through leachate was highest in the maize and ginger strip cropping plot (15 kg/ha). Its loss was 10.7 kg/ha from maize and bean strip cropping and 10.2 kg/ha from the control plot (Fig. 4.12 b). K loss through leaching was slightly higher in the early-monsoon period than in the mid- and late-monsoon periods. he differences between the mean of interventions and the control as well as between the two interventions was insignificant for NO_3-N and K leaching ($P \geq 0.20$).

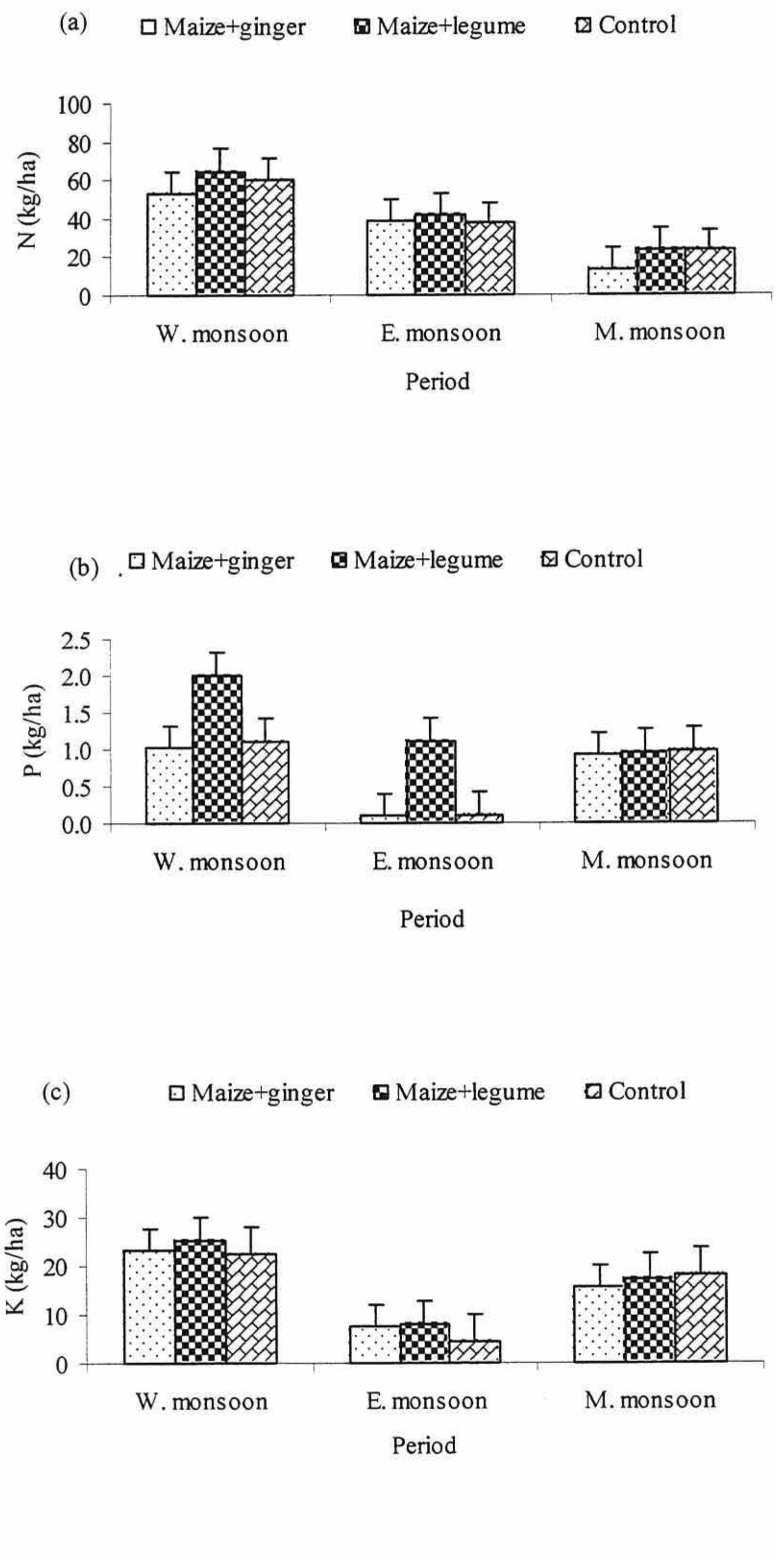


Fig. 4.10 Leachate nutrient (a) NO_3-N, (b) P and (c) K (Nayatola, 2000).

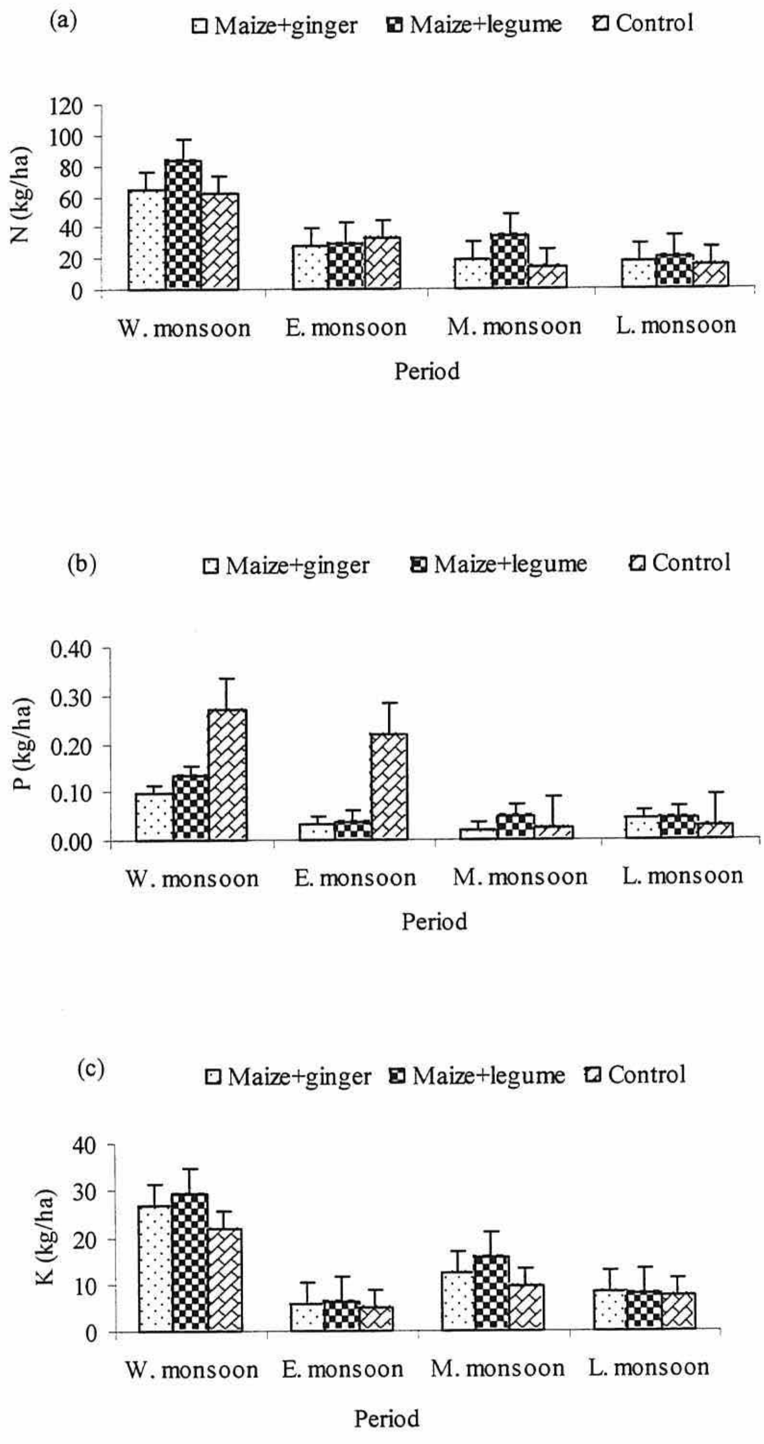


Fig. 4.11 Leachate nutrient (a) NO_3-N, (b) P and (c) K (Nayatola, 2001).

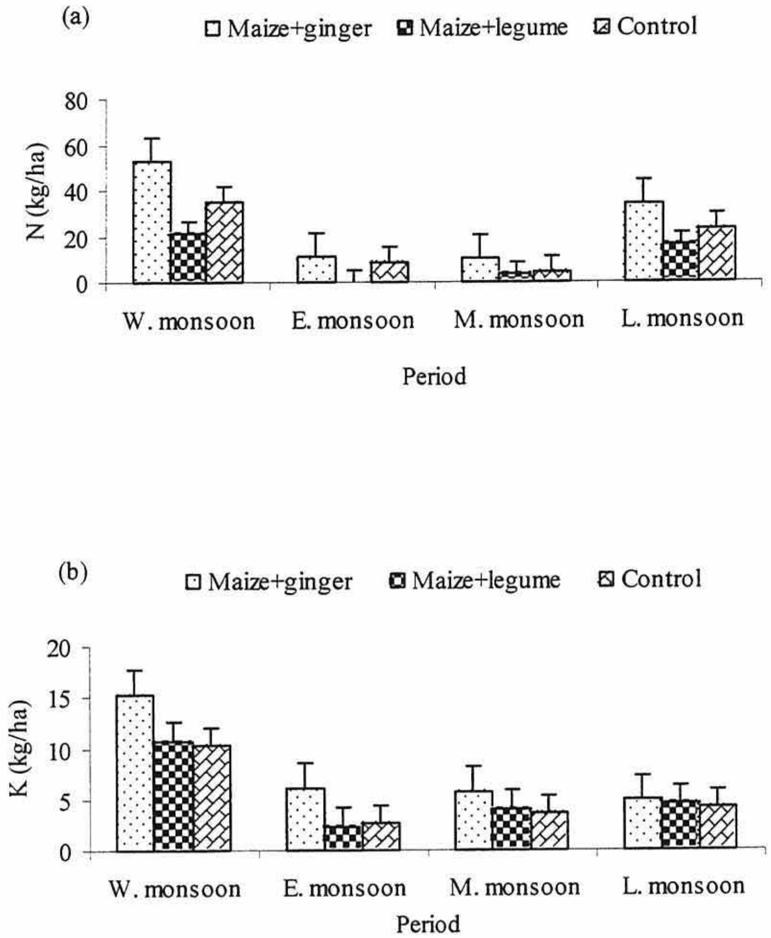


Fig. 4.12 Leachate nutrient (a) NO_3-N, and (b) K (Nayatola, 2002).

4.3.8 Soil moisture

There was no significant difference in soil moisture content between the treatments in the years 2001 and 2002 ($P > 0.05$). However, it was slightly higher in maize and ginger strip cropping ($0.35 m^3/m^3$) than in maize and legume strip cropping and the control plot in 2001. It was the same in all treatments ($0.27 m^3/m^3$) in 2002. Soil moisture content was plotted against cumulative rainfall for control and intervention plots and data are presented in Figs. 4.13 and 4.14. These figures show that the soil moisture content was lowest ($0.19 m^3/m^3$) in the early-monsoon and increased to 0.34m^3/m^3 in the late-monsoon in the control plot. Similarly, it was lowest (0.20 m^3/m^3) in the early-monsoon and increased to 0.33 m3/m3 at the end of the monsoon season in the intervention plots in 2001. In 2002 soil moisture content reached its highest (0.59 m^3/m^3) at the onset of rainfall and decreased by the middle of July (0.18 m^3/m^3). It remained below 0.32 m^3/m^3 in the late season in the control plot. The moisture content trend over the different periods was similar in both intervention and control plots. However, there was a general increase in soil moisture content with an increase in rainfall, leachate and runoff in 2001 and a general decrease with increasing rainfall, leachate and runoff in 2002. The high soil moisture content in the early-monsoon period followed by a decline later indicated that rainfall intensity was high in the early-monsoon period and then decreased. During rainfall of high intensity water accumulates in the upper soil layer due to constant infiltration. This could create over-saturated soil, resulting in a high soil moisture content.

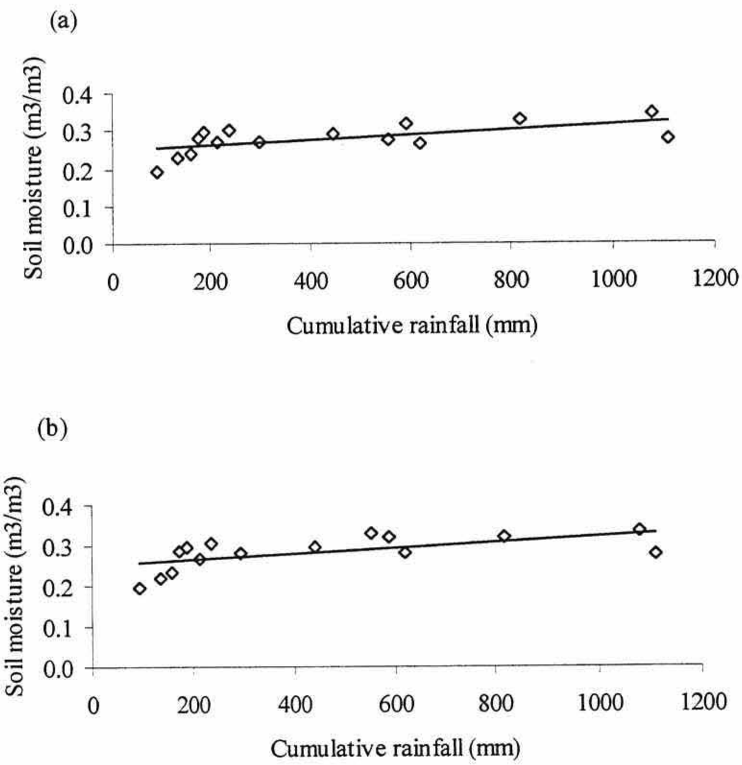
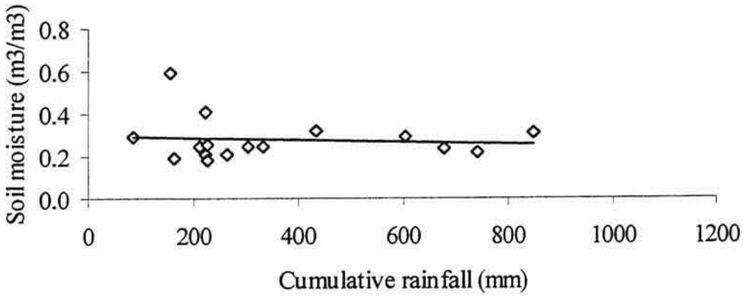


Fig.4.13 The relationship between soil moisture and cumulative rainfall in (a) control plot and (b) intervention plot (Nayatola, 2001).

(a)



(b)

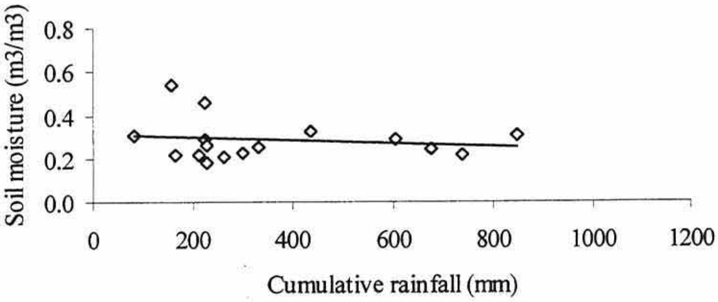


Fig. 4.14 The relationship between soil moisture and cumulative rainfall in (a) control plot and (b) intervention plot (Nayatola, 2002).

4.3.9 Soil fertility status

pH

No significant change in pH was observed in the three years of treatment. However, in the third year pH decreased in the intervention plots compared with the control plot (Table 4.3). Initial soil analysis gave a mean pH value of 5.7 and after 3 years the pH value was remained same (5.7) in each intervention plot but it had increased to 5.9 in the control plot. The difference between the mean of interventions and control was significant (P = 0.02). The two interventions did not differ significantly from each other (P = 0.56). The plot positions were significantly different in pH (P = 0.08). The top of the plot had a higher pH (5.8) than the lower position of the plot (5.7).

Table 4.3 Effect of treatments on soil pH at Nayatola (2000 - 2002)			
Treatment	2000	2001	2002
Maize/ginger strip	5.9	6.1	5.7
Maize/ legume strip	5.9	6.2	5.7
Control (farmers' practice)	5.9	6.2	5.9
SED	**0.08**	**0.07**	**0.06**
Plot position			
Top (A)	5.9	6.2	5.8
Middle (B)	5.9	6.1	5.8
Bottom (C)	5.9	6.1	5.7
Mean	**5.9**	**6.2**	**5.8**
SED	**0.09**	**0.03**	**0.05**

Organic carbon

There was no significant difference in terms of organic carbon content between the treatments (Table 4.4). The initial soil sample analysis gave a mean of 10.73 g/kg organic carbon. Soil sample analysis showed that there was no significant difference between the treatments (P = 0.17) or between the plot positions (P = 0.73) for organic carbon content in the soil after crop harvest in 2000. Organic carbon in maize and ginger strip cropping was 14.2 g/kg, higher than the control and initial values. Treatments were found to be significantly different (P = 0.06) but there was no significant difference between plot positions (P = 0.29) for organic carbon content in 2001. In the second year organic carbon increased to 15.6 g/kg in maize and ginger strip cropping. There was no significant difference between the treatments (P = 0.85) or plot positions (P = 0.10) in 2002. However, organic carbon content decreased in all plots. There was no significant difference between the mean of interventions and control or between the two interventions in the third year.

Table 4.4 Effect of treatments on soil organic carbon (g/kg) at Nayatola (2000 -2002)			
Treatment	2000	2001	2002
Maize/ginger strip	14.20	15.60	10.86
Maize/ legume strip	11.40	15.50	11.58
Control (farmers' practice)	13.00	14.90	10.95
SED	**1.89**	**0.69**	**1.38**
Plot position			
Top (A)	12.90	13.10	10.71
Middle (B)	12.30	15.20	11.38
Bottom (C)	13.40	15.20	11.30
Mean	**12.87**	**14.43**	**11.13**
SED	**1.32**	**0.42**	**0.32**

Total N

There was no significant difference between treatments or between plot positions in total soil nitrogen content (Table 4.5). The total N content in the initial soil sample was 1.3 g/kg and it increased to 1.4 g/kg after 3 years in maize and ginger strip cropping. The difference between the mean of interventions and control and also between the two interventions was insignificant ($P = 0.30$ and $P = 0.87$ respectively).

Table 4.5 Effect of treatments on total soil N (g/kg) at Nayatola (2000 - 2002).			
Treatment	2000	2001	2002
Maize/ginger strip	2.4	1.1	1.4
Maize/ legume strip	2.2	1.0	1.3
Control (farmers' practice)	2.1	0.9	1.3
SED	**0.04**	**0.09**	**0.12**
Plot position			
Top (A)	2.3	1.0	1.3
Middle (B)	2.2	1.0	1.3
Bottom (C)	2.2	1.0	1.4
Mean	**2.2**	**1.0**	**1.3**
SED	**0.05**	**0.04**	**0.05**

Available P

Treatments and plot positions were not found to make a significant difference in terms of soil P content following crop harvest in 2000 and 2001. However, there was a significant difference between the treatments in 2002 (Table 4.6). Soil from maize and legume strip cropping had the highest P content (31.4 mg/kg). The control value was 27.3 mg/kg and the initial value was 12.9 mg/kg. The difference in P content between the mean of interventions and control as well as between the two interventions was significant (P = 0.01 and P = 0.03 respectively). P content even increased in the control compared with the bench mark value. This could be due to a decrease in the loss of fertile soil and/or plant residues from the soils.

Table 4.6 Effect of treatments on soil P (mg/kg) at Nayatola (2000 - 2002).

Treatment	2000	2001	2002
Maize/ginger strip	21.6	29.9	28.8
Maize/ legume strip	22.5	32.0	31.4
Control (farmers' practice)	24.8	27.2	27.3
SED	**2.55**	**1.92**	**0.98**
Plot position			
Top (A)	19.9	29.9	29.6
Middle (B)	23.7	30.8	29.4
Bottom (C)	25.3	28.4	28.5
Mean	**23.0**	**29.7**	**29.2**
SED	**2.11**	**0.69**	**0.52**

Exchangeable K

There were no significant differences between the treatments or between the plot positions in terms of soil K in any of the three years (Table 4.7). K decreased in maize and ginger strip cropping and increased in maize and cowpea strip cropping compared with the control in 2000. K content in both the interventions was higher than that in the control in 2001. K was lower (160.8 mg/kg) in the maize and ginger strip and higher (172.7 mg/kg) in the maize and legume strip cropping plot compared with control plot (165.7 mg/kg) after the three years. K content was lower in the different treatments than the initial value (250.6 mg/kg) in the last two years. There was no significant difference in exchangeable K between the mean of interventions and control (P = 0.89) or between the two interventions (P = 0.22). Maize and ginger strip cropping resulted in more water percolation, results showing increased K leaching from soils with intervention.

Table 4.7 Effect of treatments on soil K (mg/kg) at Nayatola (2000 - 2002).			
Treatment	2000	2001	2002
Maize/ginger strip	307.7	159.2	160.8
Maize/ legume strip	387.2	149.7	172.7
Control (farmers' practice)	377.1	140.8	165.7
SED	**43.8**	**16.7**	**8.9**
Plot position			
Top (A)	348.2	145.5	163.8
Middle (B)	355.5	140.2	164.9
Bottom (C)	368.3	163.9	170.5
Mean	**357.0**	**149.9**	**166.4**
SED	**32.8**	**14.8**	**6.6**

Cation exchange capacity (CEC)

There was no significant difference in the cation exchange capacity between the treatments or plot positions (Table 4.8). The maize and ginger strip cropping plot had CEC of 23.4 meq/100g, the maize and legume strip cropping plot had CEC of 24.0 meq/100g and the control plot had CEC of 23.8 meq/100 g soil after crop harvest in 2002. There was a drastic reduction in CEC from the initial value of 52.5 meq/100 g soil. There was no significant difference between the mean of interventions and control or between the two interventions (P = 0.51 and P = 0.64 respectively).

Particle size distribution

There was no significant difference in soil particle size composition between the treatments or plot positions (Table 4.8). The sand, silt and clay distribution within the soil was 381, 403 and 216 g/kg respectively in the case of maize and ginger strip cropping; 386, 401 and 212 g/kg in maize and legume strip cropping; and 382, 401 and 217 g/kg in the control plot. The initial values were 461, 341.1 and 198.2 g/kg of sand, silt and clay respectively. There was no significant difference between the mean of interventions and the control or between the two interventions. Results showed a reduction in sand and an increase in silt and clay irrespective of treatment compared with initial values. They also show that there is a higher loss of sand particles compared with other small particles.

Table 4.8 Effect of treatments on CEC and particle size distribution in soil at Nayatola (2002).				
Treatment	CEC (meq/100 g)	Sand g/kg	Silt g/kg	Clay g/kg
Maize/ginger strip	23.4	381.3	402.5	216.1
Maize/ legume strip	24.0	386.3	401.3	212.4
Control (farmers' practice)	23.8	382.0	401.3	216.7
SED	**1.40**	**15.91**	**9.94**	**12.80**
Plot position				
Top (A)	23.3	387.3	392.5	220.2
Middle (B)	24.8	389.4	395.1	215.6
Bottom (C)	23.1	373.1	417.5	209.4
Mean	**23.7**	**383.2**	**401.7**	**215.1**
SED	**0.97**	**9.73**	**9.30**	**5.30**

4.3.10 Crop yields and economy

Farmers applied FYM at the rate of 26.2 t/ha (average) to the experimental plots in 2001 and 15.9 t/ha (average) in 2002. With these amounts of manure, existing local agronomic practices and changes in climate during the crop growing periods, fluctuations in crop production occurred. The yields from different treatments were converted into revenue per unit area (Rs/ha) and the treatments were compared for economic value.

Treatment differences were significant in 2000 (P = 0.02), 2001 (P = 0.04) and 2002 (P = 0.01) in terms of net income. In 2000 the maize and ginger strip cropping gave the highest net income of 18110 Rs/ha. The maize and cowpea strip cropping gave the lowest net income (9236 Rs/ha) because there was no yield from the cowpea strips. The control plot gave an income of 15332 Rs/ha. In 2001 the maize and ginger strip cropping gave the highest net income (31868 Rs/ha) [Table 4.9]. Maize and soybean strip cropping gave the lowest net income as there was a poor soybean yield. In 2002 the maize and ginger strip cropping gave the highest net income (33647 Rs/ha) compared with the control (9398 Rs/ha).

Straw yield was not significantly affected by intervention in any year. However, the control plot produced the highest straw yield throughout (Table 4.10). The legume crop residue was not added to the intervention plots in 2000 and 2002. Besides the poor yields of soybean in more fertile plots (it has a low requirement for N), soybean produces less biomass compared with maize. The straw yields were therefore lower in both the intervention plots.

Table 4.9 Income (Rs/ha) from strip cropping at Nayatola (2000 - 2002)

Treatment	2000	2001	2002
Maize/ginger strip	18110	31868	33647
Maize/ legume strip	9236	18820	6420
Control (farmers' practice)	15332	21089	9398
Mean	**14226**	**23925**	**16488**
SED	**2500**	**4377**	**5660**

Table 4.10 Straw yields (kg/ha) on an oven dry basis from strip cropping at Nayatola (2000 – 2002)

Treatment	2000	2001	2002
Maize/ginger strip	2198	4236	1931
Maize/ legume strip	2885	4518	2001
Control (farmers' practice)	4025	5122	2321
Mean	**3036**	**4625**	**2048**
SED	**758.2**	**739.4**	**323.3**

4.3.11 NPK uptake in crop

NPK contents in grain, crop residues and ginger rhizomes were analysed during 2002. NPK uptake was higher in maize and ginger strip cropping than in the control (Table 4.11). NPK uptake results were only obtained from the maize in the maize and legume strip cropping system because the legume crop died during the growth period to give higher NPK content in soil. Due to less number of maize plants total uptake was low in maize and legume strip cropping.

Table 4.11 NPK uptake by crops at Nayatola (2002).			
Treatment	N (kg/ha)	P (kg/ha)	K (kg/ha)
Maize/ginger strip	48.0	14.6	58.8
Maize/ legume strip	35.2	9.9	43.2
Control (farmers' practice)	45.7	13.4	45.3
Mean	**43.0**	**12.6**	**49.2**
SED	**7.08**	**1.89**	**5.80**

4.4 DISCUSSION

The seasonal distribution pattern and amount of rainfall varies from year to year in Nayatola, a site representative of sloping land cultivation with low to medium rainfall. Most soil loss occurs either just after the maize has been planted or when the field has just been prepared for maize planting. Soil loss can be extreme especially during the pre-monsoon period when intense rainfall occurs on ploughed fields having bare and vulnerable soil (Gardner *et al.*, 2000). Runoff is reduced in maize and ginger strip cropping if there is an increase in water infiltration due to mulching in the early-monsoon period. Soil loss is therefore reduced. However, leaching of nutrients can be increased although this was not the case in the first two years. The importance of soil loss lies in the loss of plant nutrients. Youmin and Junhua (2002) reported that, in forests, soil litter cover decreases soil erosion by 9.15 times. Farmers do not give priority to soil management. They adopt a wide range of profitable and less resource-demanding soil and water conservation technologies (McDonald and Brown, 2000; Cramb *et al.*, 2000). The farmers are convinced that maize and ginger strip cropping is more profitable than growing maize alone. Only a few rainfall events produce enough kinetic energy to cause soil loss during the pre-monsoon period. More than 75 % of the annual loss occurs during the early-monsoon (2001 and 2002). These results are similar to the findings of Gardner *et al.* (2000) and Carver and Nakarmi (1995). The proportion of rainwater lost to surface runoff is very low (less than 13 mm). Low rainfall followed by drought and plant cover at the surface encouraged more water to be absorbed into the soil rather than to be lost to surface runoff. 2000 was an exception as high loss followed in the early-monsoon period. This might have been due to a change in the rainfall pattern and delay of crop planting along with field operations during late periods of the season. The eroded sediment contains a very high level of organic carbon (minimum of 50 g/kg) compared with the bench mark soil sample value (10.7 g/kg) and a very high level of available phosphorus (60 mg/kg) compared with the bench mark soil sample (12.9 mg/kg).These elements are amongst the most important nutrients lost from the soil. A low surface runoff causes a small loss of soluble nutrients but high infiltration causes a significant amount of N and K leaching. The interventions had no effect on the leaching of these nutrients. Infiltration of rainwater plays an important rôle in the loss of N and K from the root zone. Greater leaching was observed in the first and second years and less in the third year. The amount of nutrient leaching is related to the amount of water percolation. A high frequency of rainfall results in the continuous wetting of the soil, allowing more leaching of nutrients. If drought occurs after rainfall then wetting and drying enhances K fixation in the soil and results in less K leaching (Zeng and Brown, 2000).

Rainfall is the main factor causing soil loss because there is always a strong and positive correlation between amount of rainfall and production of kinetic energy ($r \geq 0.78$). Variation in the correlation between rainfall or KE and soil loss was observed in different years. This might be due to other factors affecting soil loss. The quadratic relationship might exist between soil loss and KE because, when soil is friable and bare, soil loss occurs even with low energy rainfall. Once all friable soil has been removed, or when enough plant growth has occurred, the soil can resist loss through high energy rainfall.

The total annual loss of nutrients was calculated for the different treatments. In the control plot a total of 84.8 kg/ha N was lost through leaching, runoff, sediment and crop uptake. Similarly, totals of 13.8 kg/ha P and 58.3 kg/ha K were lost from the control plot. Application of manure provides the source of nutrients in the soil and there is some contribution from rainwater. The total intake of nutrients was 96.1 kg/ha N, 17.9 kg/ha P and 99.0 kg/ha K (Table 4.12). There was no nutrient mining in the control plot or in the maize and legume strip cropping plot with the 15.9 to 26.2 t/ha FYM application but each year N was mined at the rate of 1.8 kg/ha in the maize and ginger strip cropping plot. The legume crop grown was not consistent enough throughout the testing seasons to determine its effect on nutrient loss through leaching.

Table 4.12 Annual nutrient status in the sloping bari lands with low to medium rainfall (Nayatola, 2002).

Sources of Nutrients		Maize and ginger strip cropping			Maize and legume strip cropping			Control		
Status	Sources	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Gain	Rain	7.60	0.17	3.03	7.60	0.17	3.03	7.60	0.17	3.03
Gain	FYM	92.23	19.22	95.22	89.5	21.35	100.36	88.45	17.73	95.97
Total gain		99.83	19.39	98.25	97.1	21.52	103.39	96.05	17.90	99.00
Loss	Crop uptake	48.02	14.58	58.77	35.23	9.87	43.15	45.7	13.40	45.64
	Leaching	52.86	0.10	15.21	21.74	0.13	10.67	34.81	0.27	10.20
	Runoff	0.15	1.02	0.65	0.36	0.03	1.49	0.51	0.06	1.96
	Sediment	1.06	0.01	0.07	1.63	0.03	0.19	3.81	0.07	0.46
Total loss		101.63	14.71	74.70	58.96	10.06	55.50	84.83	13.80	58.26
Inherent in Soil		2724.00	57.70	321.60	2688.00	62.72	345.40	2504.00	54.56	331.40
Overall status in the soil		**-1.80**	**4.69**	**23.56**	**38.14**	**11.46**	**47.90**	**11.22**	**4.10**	**40.74**

CHAPTER 5

INTERVENTIONS TO MINIMISE SOIL AND NUTRIENT LOSSES IN LANDRUK, A SITE REPRESENTATIVE OF HIGH RAINFALL AND THE BENCH TERRACING CULTIVATION SYSTEM

5.1 INTRODUCTION

Nepal is a small country having a large variation in rainfall pattern, rainfall distribution, land use and cropping systems. The rainfall is higher in the east and lower in the west. A bench terrace land use system extends from the east to the western mountains and hills. The southern parts of Annapurna, Machhapuchhre (Himalayas) and around the Pohkara valley in the Kaski district receive high rainfall ranging from 3000 to more than 5000 mm annually (Carson *et al.*, 1986). This area consists mostly of rainfed upland (*bari* lands) in the middle hills ranging from 900 to 1700 m altitude asl. Maize and millet are traditionally grown in this area in which land is sensitive to soil erosion because of high rainfall (Mawdesley *et al.*, 1998). Vaidya *et al.* (1995) also reported that rainfall has a significant effect on soil fertility because it causes a loss of topsoil.

Terracing a slope is one of the measures used to control soil erosion (Chen and Lingqin, 2002) and it reduces soil loss by 80 % on 25 to 60 % slopes in the Philippines (Damo, 1994). The terracing system is used on 30 % of arable land in Nepal (Pratap and Watson, 1994) and is traditionally employed on sloping farmland. High rainfall and the existing maize cultivation system are major causes of soil erosion in these areas. Soil loss from terraces at Landruk was found to be 1.2 to 11.9 t/ha, and run-on was found to contribute to additional soil loss shown by sediment measurements in open plots (Gardner *et al.*, 2000). It has also been reported that considerable amounts of N and K (4 - 20 kg/ha) have been lost through leaching. Farmers of the middle hills have fewer crop and cropping system choices as the altitude increases, especially towards the northern part of the country. Maize/millet/fallow is the dominant cropping system in high rainfall areas and above 900 m in the rainfed *bari* lands of the Kaski district. In alternate years farmers grow wheat or barley after the maize crop. Manure resources are declining and cultivated fields are also receiving less manure. It is traditional to use *in situ* manuring. Cattle or sheep and goats are kept on the terraces for 2 or 3 nights before being moved to different terraces (Subedi *et al.*, 1995). This practice is carried out after first crop harvest and before planting of the second crop. Manuring priority goes to maize and large amounts are usually applied in order to ensure satisfactory crop yields. Farmers express dissatisfaction if less than the usual amount of manure is used. Farmers do not generally apply manure to millet.

The number of livestock is decreasing due to a decline in fodder supplies. This has ultimately meant a reduction in the manuring of fields. In addition, most of the nutrients applied via manure to the field are lost with sediment loss, runoff or through leaching during rainfall. Farmers are aware of this loss but do not know how to prevent it other than by application means. Technologies are required to manage natural resources and should be based on farmers' needs. Efficient use of soil available nutrients in crop production can minimise the cost of fertilizer application for the same level of production and local technology can be sustainable (Neimeijer, 1998). If farm households are involved in the technology development process then fertilizer efficiency is increased through integrated nutrient management based on nutrient saving (Jager *et al.*, 1998). The main objective of the research therefore is to evaluate local knowledge for soil and water conservation in the remote and high rainfall areas of the middle hills based on farmers' needs. In the past diversion of run-on has been used for runoff control (Shrestha, 2000) and it can be easily adopted. Planting of the terrace riser with good quality grass not only resolves the problem of fodder scarcity but also harvests nutrients. Grasses in risers tap the nutrients flowing from terraces. If the grasses are deep rooted they recycle nutrients from soil depth. Legume also fixes nitrogen from the atmosphere.

5.2 MATERIALS AND METHODS

Landruk was selected as a site representative of high rainfall and the bench terracing system. Nine previously established research plots (varying in size) in five farmers' fields were at this site (Gardner *et al.*, 2000). Like Nayatola, the control treatment was assigned to previously established plots (one in each farm). If a farm had an additional pre-existing plot, one of the interventions was randomly assigned to this plot. Otherwise, interventions were assigned to the new plots adjoining the previously established plot. Thus five blocks each containing three experimental plots was established in the five farmers' fields at this site. The first intervention involved run-on control by closure of the treated plot (closed plot) and the second intervention involved the planting of risers with grass to create a runoff barrier, leaving the plot open to allow run-on from the top (grass plot). Run-on was maintained in the third plot as in farmers' practice (control plot). Following the same procedure used at Nayatola, these treatments were randomly assigned to each block. However, the control treatment was only assigned to pre-existing plots. The cumulative width of all the terraces in a plot was 20 m and the length 5 m.

In 2000 maize was planted in the third week of April (harvested in September). Finger millet was transplanted in the second week of June (harvested in December) except in the fourth block in which maize was planted in March and, after harvest in September, naked barley was planted. The naked barley was harvested in March. In the third week of June *Flemingia macrophylla* was sown on the top of the terrace risers in each block in the plots assigned for the second intervention. In the last week of May, slips of another fodder grass, *Setaria aneps,* were also planted into the risers below the *Flemingia macrophylla.* The *Flemingia macrophylla* failed to germinate and the *Setaria aneps* established poorly or not at all.

In 2001 maize/naked barley was planted in all blocks except the fourth block in which maize/millet was planted. *Flemingia macrophylla* seeds were soaked in water for 24 hours before being sown in the risers. The seeds germinated but plant growth was very slow. They were outcompeted by native and wild grasses and failed to survive. *Setaria aneps* slips were planted densely in the second week of May. These established satisfactorily although the cover was thin; gap filling was required in successive years.

In 2002 the cropping system and crops were the same as in the first year in all blocks and *Setaria aneps* slips were also replanted densely to fill gaps in the risers of the second intervention plots. The application of farmyard manure to each plot was recorded during 2001 and 2002 but nutrient (NPK) content was only analysed in samples taken in 2002 (Table 5.1). Data on runoff, sediment and leachate were recorded and samples were analysed for nutrients especially for NPK contents. Crop yields were recorded from all three seasons. Grass production was only recorded in the third year (2002). Samples of crop yield, residues, grass and manure were analysed for NPK in the third year. Soil samples were also collected after the last crop harvest in each season except from the fourth block in which soil samples were collected whilst the crop was standing in the field (2002). All samples were analysed for nutrient content.

Table 5.1 FYM and its NPK and moisture contents during application in the experimental plots (Landruk, 2001-2002).

Block	FYM 2001	FYM 2002				
	(t/ha)	(t/ha)	Moisture content (g/kg)	N (kg/ha)	P (kg/ha)	K (kg/ha)
1	42.7	21.3	63.8	118.2	23.1	153.9
2	41.3	20.7	65.1	185.6	31.5	64.6
3	32.0	16.0	78.0	86.0	18.6	41.5
4	16.0	8.0	81.0	32.0	5.2	14.1
5	20.0	10.0	58.4	63.7	11.9	77.5
Mean	30.4	15.2	69.3	97.1	18.1	70.3

5.3 RESULTS

5.3.1 Rainfall and its erosivity

Total monsoon rainfall was 3193, 3692 and 3441 mm during the years 2000, 2001 and 2002 respectively. The distribution of rainfall is presented in Fig. 5.1. Periods of rainfall are categorised into three parts. Rainfall occurring before May 31st is early-monsoon rainfall for this area. Farmers grow most of their crops in this period. Rainfall occurring during June and July is mid-monsoon rainfall in which about 50 % of rainfall occurs. Farmers tend to transplant finger millet in this period. Rainfall occurring after 31st July is categorised as late-monsoon rainfall. Farmers harvest maize and prepare the land for winter crops in this period.

In 2000 the early-monsoon rainfall was 241 mm, producing a total KE of 1661.3 MJ mm/ha/h (calculated as described in chapter 4) and a maximum KE of 440.4 MJ mm/ha/h in one rainfall event. The mid-monsoon rainfall was 1701 mm, producing a total KE of 18553.7 MJ mm/ha/h and a maximum KE of 2479.8 MJ mm/ha/h in one rainfall event. The late-monsoon rainfall was 1278 mm, producing a total KE of 13392.3 MJ mm/ha/h and a maximum KE of 2453.6 MJ mm/ha/h in one rainfall event. The total KE of the whole season was 19071.9 MJ mm/ha/h and the maximum KE in one rainfall event was in the mid-monsoon period.

In 2001 the early-monsoon rainfall was 432 mm, producing a total KE of 5189.1 MJ mm/ha/h with a maximum KE of 1023.4 MJ mm/ha/h in one rainfall event. The mid-monsoon rainfall was 1699 mm with a total KE of 7756.6 MJ mm/ha/h and a maximum KE of 5028.9 MJ mm/ha/h in one rainfall event. The late-monsoon rainfall was 1561 mm, producing a total KE of 6126.2 MJ mm/ha/h and a maximum KE of 2735.2 MJ mm/ha/h in one rainfall event. The total KE produced by rainfall was therefore 33607.2 MJ mm/ha/h. The highest KE was observed in the mid-monsoon.

In 2002 early-monsoon rainfall (before May 31) was 521 mm which produced a total kinetic energy of 7457.9 MJ mm/ha/h. During this period the maximum KE was 1278.0 MJ mm/ha/h on May 6 with 35 mm rainfall. The mid-monsoon rainfall was 1706.7 mm producing KE of 25310.6 J. There was 111 mm rainfall on June 26 producing KE of 4104.4 MJ mm/ha/h in one event. The late-monsoon rainfall was 1213 mm, producing total KE of 19471.4 MJ mm/ha/h. During this period the maximum KE was 4931.4 MJ mm/ha/h on 27th September. Total rainfall was therefore 3441 mm and total KE was 52240.0 MJ mm/ha/h over the whole season, the maximum KE produced was in the mid-monsoon period. This rainfall pattern affects soil detachment, movement and loss. However, other factors interact with the effect of rainfall to influence soil erosion.

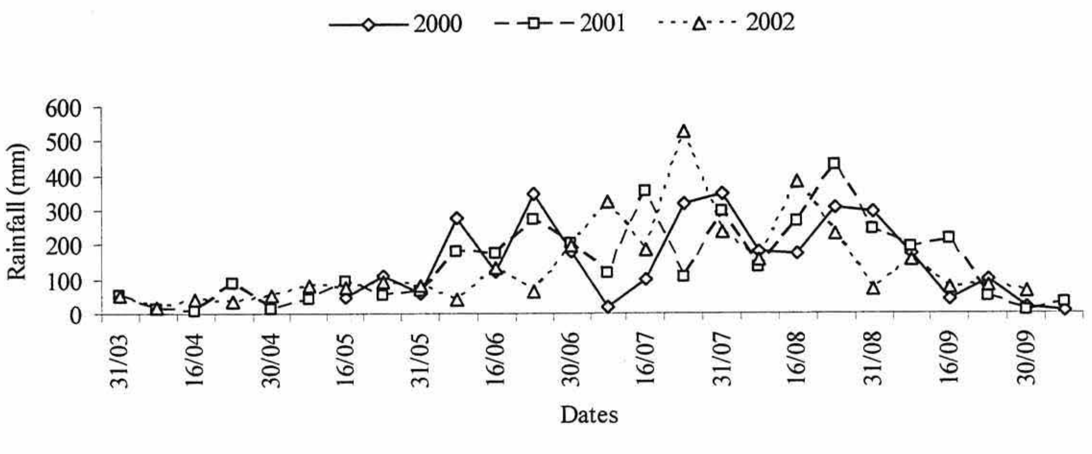


Fig. 5.1 Rainfall at Landruk (2000-2002).

5.3.2 Runoff

In 2000 runoff over the whole season was 5.5 % of rainfall from the closed plot, 9.3 % from the grass plot and 5.6 % from the control plot (Fig. 5.2a). Runoff increased from the early-monsoon period through to the late-monsoon period in all treatments. The effect of interventions on runoff was insignificant (P = 0.19) [Fig.5.3 a]. The lowest total runoff for the whole season was 176.7 mm from the closed plot followed by 179.6 mm from the control plot. The grass plot had the highest runoff (296.5 mm). Runoff in the early-monsoon showed the least significant difference (P = 0.23) amongst the treatments. It was 1.7 mm from the closed plot, 4.1 mm from the grass plot and 2.0 mm from the control plot. Runoff in the mid-monsoon did not differ significantly amongst the treatments (P = 0.82). It was 92.5, 100.1 and 82.3 mm respectively from the closed plot, grass plot and the control plot. Runoff in the late-monsoon did not differ significantly amongst the treatments. It was 82.5, 182.4 and 95.3 mm from the closed plot, grass plot and the control plot respectively. Runoff was higher from the grass plot, because of soil disturbance during grass planting. A comparison was made between the average of the interventions and the control as well as between the two interventions in terms of total runoff for the whole season. The differences between intervention and control and between the two interventions were insignificant (P = 0.36 and P = 0.12 respectively). A greater difference between the two interventions was indicated. The closed plot reduced runoff to a greater extent than the grass plot. There was no significant difference between intervention and control due to increased runoff from the grass plot.

In 2001 runoff over the whole season was 7.3 % from the grass plot, 4.7 % from the closed plot and 4.7% from the control plot. Runoff increased from the early- through to late-monsoon periods in all treatments except in the control in which the runoff % was higher in the early-monsoon than in the mid-monsoon (Fig.5.2 b). The total amount of runoff over the whole season did not differ significantly between the treatments (P = 0.17) [Fig.5.3 b]. Runoff was 173.2 mm from the control plot and 173.8 mm from the closed plot. The grass plot had the highest runoff (268.4 mm). The amount of runoff from the closed plot, the grass plot and the control plot was 13.4, 11.3 and 22.3 mm in the early-monsoon; 54.5, 115.4 and 63.1 mm in the mid-monsoon; and 106.0, 141.7 and 87.9 mm in the late-monsoon respectively. The differences were not significant in the early and late monsoon (P = 0.34 and P = 0.51) but were significant in the mid monsoon (P = 0.09). The difference between intervention and control was found to be low (*P* = 0.23) and there was a significant difference between the two interventions (*P* = 0.05) indicating that runoff is clearly reduced from the closed plot compared with that from the grass plot.

In 2002 runoff was 8.8 % of the rainfall in the closed plot, 9.96 % in the grass plot and 11.3 % in the control plot (Fig 5.2 c). There was no significant difference in total runoff between the treatments (*P* = 0.95) [Fig. 5.3 c]. The lowest runoff was 303 mm from the closed plot and the highest was 390 mm from the control plot. The grass plot gave 341mm runoff. Runoff differed the least (*P* = 0.77) between the treatments in the early-monsoon. Runoff was 52.1 mm from the closed plot, 52.3 mm from the grass plot and 60.8 mm from the control plot. There was no significant difference in mid-monsoon runoff (*P* = 0.91) between the treatments, the closed plot producing the lowest runoff (163.2 mm). The control plot gave the highest runoff (254.0 mm). The grass plot gave 164.7 mm runoff. There was no significant difference in late-monsoon runoff between the treatments (*P* = 0.63). The closed plot gave 87.5 mm runoff, higher than that from the control (75.2 mm) and less than that from the grass plot (124.7 mm). There was no significant difference between intervention and control (*P* = 0.52) or between the two interventions (*P* = 0.74). The effect on runoff was not clear between the two interventions or between the intervention and control.

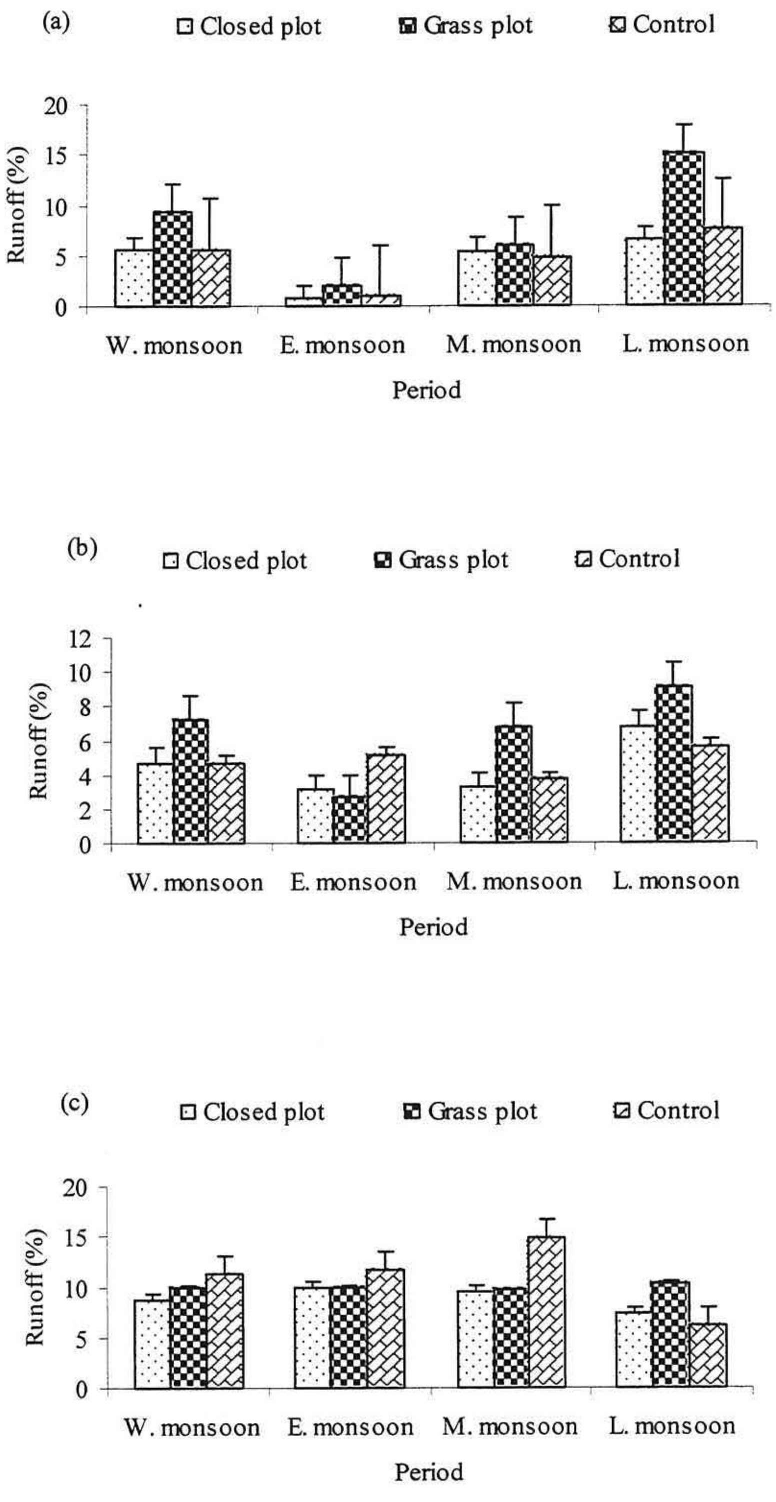


Fig. 5.2 Runoff (percentage of rainfall) during (a) 2000, (b) 2001 and (c) 2002 at Landruk.

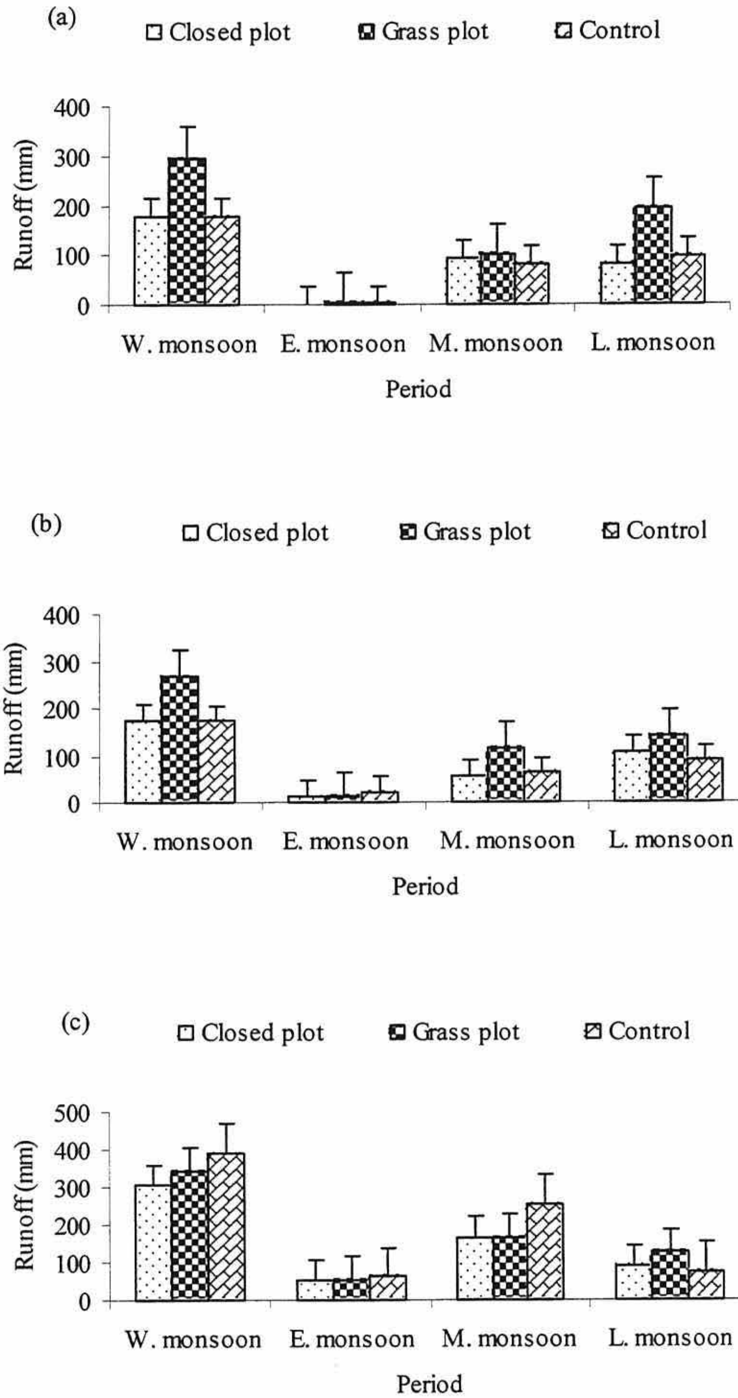


Fig. 5.3 Runoff amount (mm) during (a) 2000, (b) 2001 and (c) 2002 at Landruk.

5.3.3 Eroded sediments

Fig. 5.4 (a) shows the distribution of sediment loss in 2000. There was a significant difference in total sediment loss over the whole season ($P = 0.11$) between the treatments. The closed plot produced 994.2 kg/ha sediment compared with 2229.1 kg/ha in the control plot. The grass plot produced the highest quantity of eroded sediment (3611.2 kg/ha). The treatments differed significantly ($P = 0.03$) in the early-monsoon. In other periods differences between the treatments were insignificant ($P = 0.14 - 0.23$). There was no significant difference between the mean of interventions and control ($P = 0.94$) but there was a significant difference between the two interventions ($P = 0.03$). Results indicated that grass planted in terrace risers increased soil loss due to increased runoff. The distribution of sediment loss from the closed plot, grass plot and control plot was 38.2, 207.6 and 37.5 kg/ha in the early-monsoon period and 659.8, 2091.7 and 1888.2 kg/ha in the mid-monsoon period. Runoff sediments in the late-monsoon period were 296.3, 1306.9 and 303.5 kg/ka in the closed plot, grass plot and the control plot respectively. Runoff sediment losses were higher in the mid-monsoon compared with the early-and late-monsoon periods. Soil loss was 4.1 % in the early-monsoon period, 68.0 % in the mid-monsoon period and 27.9 % in the late monsoon period.

Fig. 5.4 (b) shows the distribution of sediment loss in 2001. Total sediment loss over the whole season did not differ significantly between the treatments ($P = 0.33$). The least sediment loss was from the closed plot (478 kg/ha) and the highest was from the grass plot (1293 kg/ha). The loss of sediment was 886 kg/ha from the control plot. The distribution of sediment loss from the closed plot, grass plot and control plot was 336.5, 832.7 and 661.6 kg/ha in the early-monsoon period; 60.5, 266.2 and 171.2 kg/ha in the mid-monsoon period and 80.8, 194.0 and 52.8 kg/ha in the late-monsoon period. Sediment losses from different plots were higher in the early-monsoon period compared with the mid- and late-monsoon periods. Sediment runoff in the control and grass plot decreased gradually from the early- to late-monsoon period. However, in the closed plot less sediment runoff occurred in the mid-monsoon compared with the late-monsoon. There was no significant difference between the mean of interventions and the control and there was no significant difference between the two interventions ($P \geq 0.15$). Soil loss was found to be 68.9 % in the early-monsoon, 18.8 % in the mid-monsoon and 12.3 % in the late-monsoon.

Fig. 5.4 (c) shows the distribution of sediment loss in 2002. Results indicated that the two cropping systems differed significantly (P = 0.11) in their soil losses through runoff. Soil loss was higher from the maize/barley (winter crop) cropping system (7385 kg/ha) than from the maize/millet inter-cropping system (4274 kg/ha). The treatments were insignificantly different (P = 0.33); the lowest soil loss was from the closed plot (4653 kg/ha) and the highest was from the control plot (7256 kg/ha). Soil loss from the grass plot was also less than from the control plot. There was no significant difference between the treatments in any monsoon period ($P \geq 0.17$). However, interventions in the early-monsoon resulted in less sediment loss (3329-3765 kg/ha) compared with the control (6020 kg/ha). Mid-monsoon loss of sediment was highest from the grass plot and least from the closed plot. Sediment loss in the late monsoon was greater from both the interventions than the control. There was no significant difference between the mean of interventions and control or between the two interventions ($P \geq 0.19$). Sediment loss was much higher in the early monsoon compared with the mid- and late-monsoons. The loss was 75.4 % in the early-monsoon, 18.2 % in the mid-monsoon and 6.4 % in the late-monsoon.

Sediment losses from the different treatments did not show a constant trend over the 3 year period. Sediment losses were higher in 2000 than in 2001 but were much higher in 2002. In 2000 soil loss was highest in the mid-monsoon but in 2001 and 2002 most soil loss occurred in the early-monsoon. Higher rainfall was recorded in 2001 than in 2000 and 2002. The grass plot experienced the most soil loss. Grasses were planted when rainfall commenced. The planting operation therefore disturbed the soils in risers, accelerating the movement of soils and increasing sediment yield from the plot.

High rainfall caused high soil loss in Landruk. Fig. 5.5 shows events of major soil loss during 2000 - 2002. In 2000 soil loss was greater with higher rainfall in the control plot and the plot of grass planted in terrace risers irrespective of period. An event of 51 mm rainfall resulted in the greatest soil loss (793 kg/ha/yr). An event of 50 mm rainfall resulted in the highest soil loss (681 kg/ha) from the grass plot. The same rainfall event resulted in a lower soil loss (85 kg/ha) from the control plot. In run-on diversion a high rainfall event resulted in a high soil loss. In the control plot lower rainfall produces a high sediment loss compared with the soil loss of the previous day with high rainfall. Run-on from longer distance increases velocity in runoff to cause more soil loss with low amount of rainfall. Only high rainfall causes a high soil loss when run-on is controlled. In 2001 a 26 mm rainfall event resulted in the highest soil loss (irrespective of treatment). Most high soil loss occurred with high rainfall usually in the early period. In 2002 soil loss was high compared with other years. Loss was greater with higher rainfall in the early period. In the case of run-on diversion erosion starts with sheet erosion in which raindrops detach soil particles and accumulated water starts to move downslope carrying soils. Run-on enters the field and starts to form rills or gullies depending on the amount and velocity of the run-on. However, sheet erosion produces less sediment than rill and gully erosion.

The regression plots showed linear and positive relationship between KE produced by rainfall and soil. It indicated that soil loss increased with KE increase in 2000 (Fig. 5.6). Soil loss increases with KE increase but a number of factors influence the relationship. When soil loss occurred during mid momsoon or after May 31st it significantly increased with KE increase. Soil loss was highly significant in the closed plot while significance was lower in the grass plot and the control. In 2001 and 2002 the regression did not show a significant linear relationship. Most soil loss events have occurred below 1000 MJ mm/ha/h and very few events to relate rainfall with high KE to soil loss. The period of rainfall, the vegetation cover and run-on might be important factors affecting KE which determines quantity of soil loss in each rainfall event.

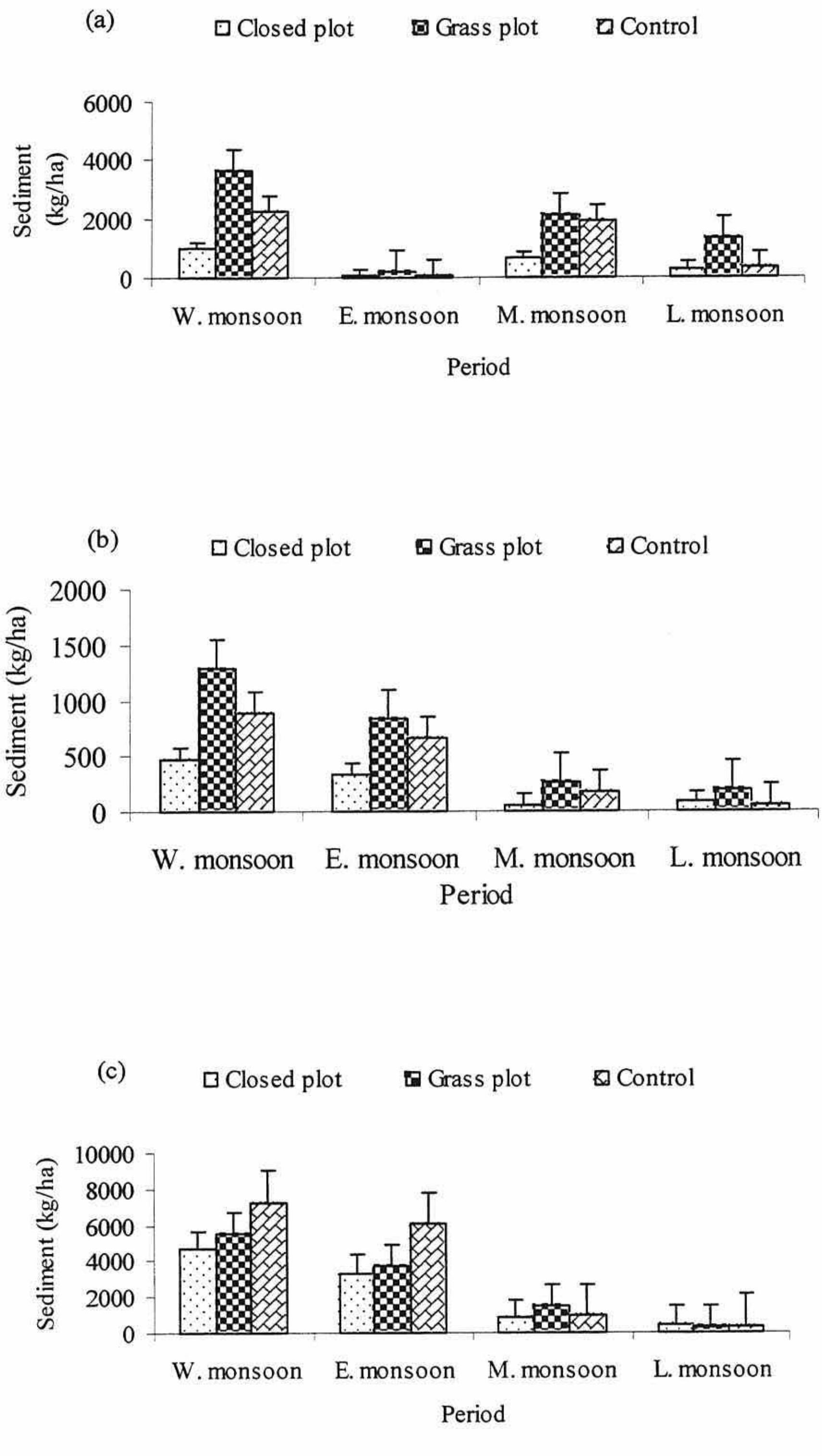


Fig. 5.4 Sediment losses from different treatments during (a) 2000, (b) 2001 and (c) 2002 at Landruk.

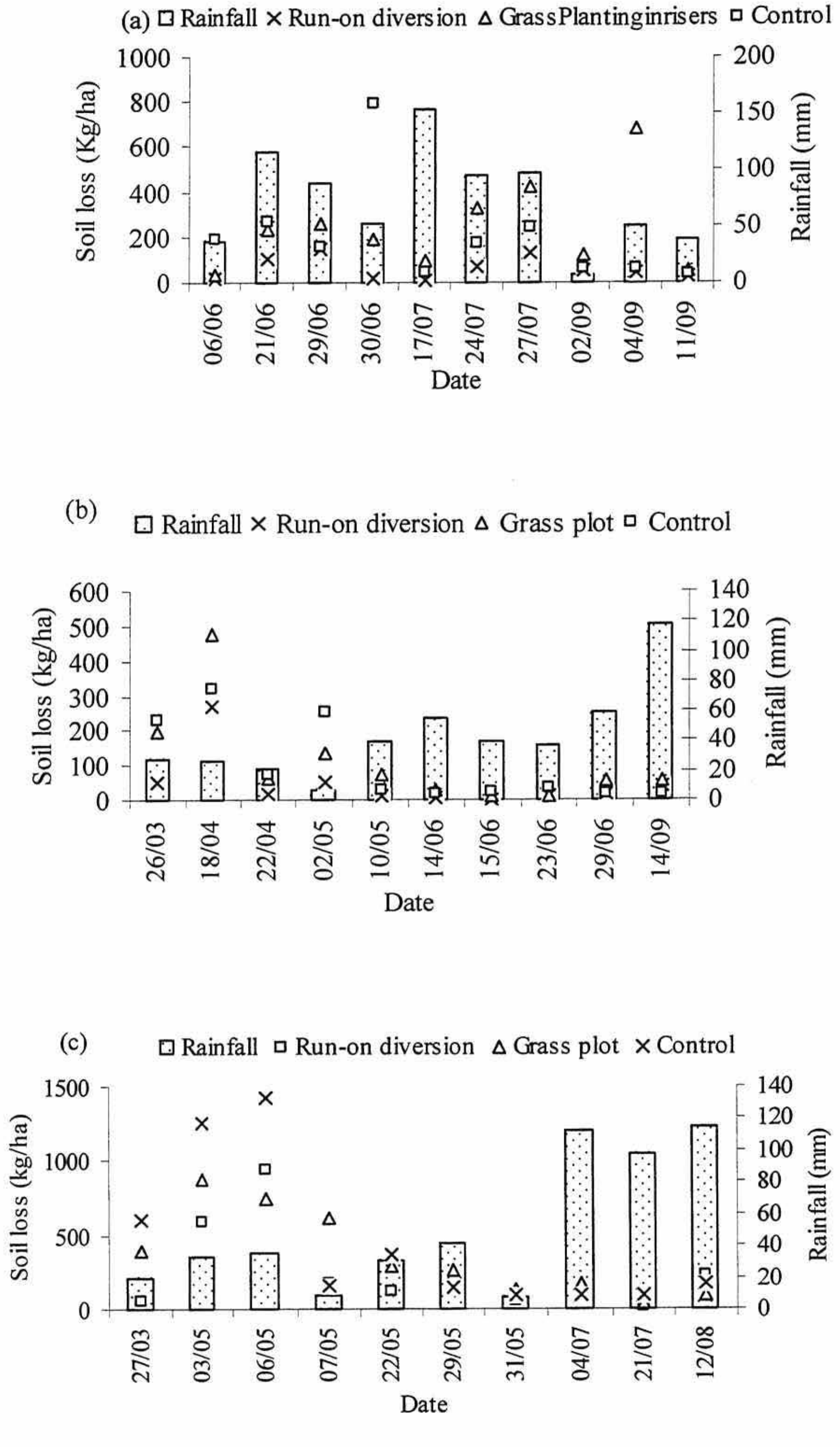


Fig. 5.5 Soil loss events during (a) 2000, (b) 2001 and (c) 2002 at Landruk.

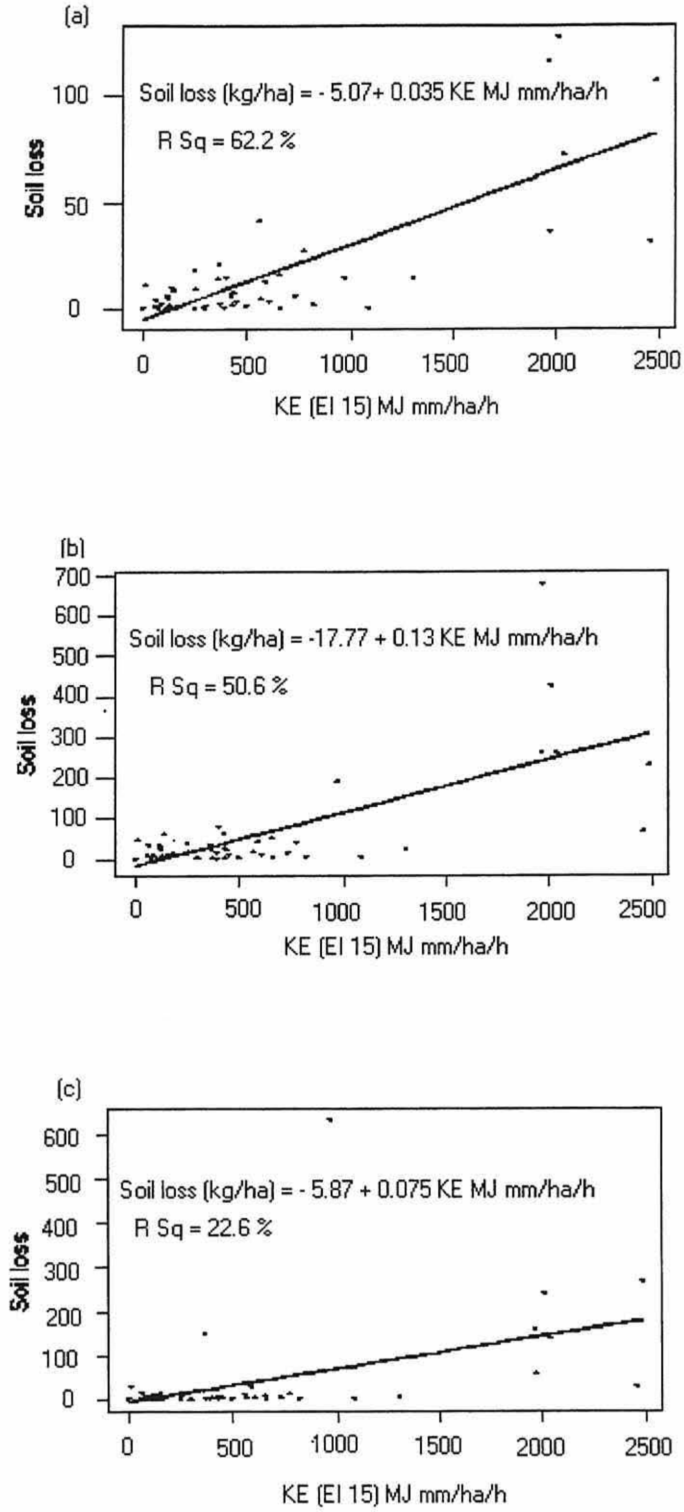


Fig. 5.6 The relationship between soil loss (kg/ha) and KE MJ mm/ha/h in (a) closed plot (b) grass plot and (c) control plot (2000 at Landruk).

5.3.4 Soluble nutrients in runoff

In 2000 filtered runoff samples were analysed for dissolved NO_3-N, P and K. There was no significant difference in N between the treatments (P = 0.62). The lowest N loss (0.7 kg/ha) was from the closed plot. 1.4 kg/ha N was lost from the grass plot. The control lost more N compared with the intervention plots (Fig. 5.7 a). There was no loss of NO_3-N from the closed plot in the early-monsoon period but there was a loss in the mid-monsoon and in the late-monsoon. The loss of NO_3-N from the grass plot was lowest in the early-monsoon and gradually increased to the late-monsoon. Losses of NO_3-N from the control plot were highest in the mid-monsoon period and lowest in the early-monsoon period. The loss of dissolved P in runoff did not exceed 0.11 kg/ha (Fig 5.7 b). Loss of P was higher from the grass plot and lower from the closed plot compared with the loss from the control plot. The loss of K was higher from the grass plot and lower from the closed plot compared with the control plot (Fig. 5.7 c). The K loss from the closed plot was highest in the mid-monsoon and lowest in the early-monsoon period. Losses of K increased from the early-monsoon through to the late-monsoon in both the grass plot and the control plot. There was no significant difference between the mean of the interventions and the control or between the two interventions ($P \geq 0.30$) for NO_3-N and K contents in runoff. However, the difference between the mean of interventions and control was significant (P = 0.08) for P content.

In 2001 the difference in loss of total NO_3-N in runoff between the treatments was significant (P = 0.09) [Fig 5.8 a]. The closed plot lost the least NO_3-N (3.4 kg/ha) and the grass plot lost the highest amount (5.6 kg/ha). The control plot lost 4.7 kg/ha. The closed plot always lost less NO_3-N compared with other plots. The loss of NO_3-N from the closed plot was highest in the early-monsoon and lowest in the mid-monsoon. The loss of NO_3-N from the control plot decreased gradually from the early-monsoon through to the late-monsoon. The loss of dissolved P in runoff from different plots did not exceed 0.2 kg/ha and there was no significant difference between the treatments (Fig. 5.8 b). The loss of K was least from the control plot (4.8 kg/ha) compared with 6.5 kg/ha from the closed plot and 9.6 kg/ha from the grass plot (Fig. 5.8 c). However, there were no significant differences between the treatments (P = 0.28).The loss of K was highest in the early-monsoon and lowest in the mid-monsoon in all interventions and control plots. The differences between the mean of interventions and control and between the two interventions were insignificant for NO_3-N, P and K contents in runoff ($P \geq 0.20$).

In 2002 runoff samples were analysed for NO_3-N and K. No significant differences were observed between different cropping systems ($P = 0.92$) or between different treatments (p = 0.85) for NO_3-N (Fig. 5.9 a). However, N loss through runoff was higher (4.9 kg/ha) from the maize/millet cropping system than from the maize/barley cropping system (4.4 kg/ha). The closed plot lost the least NO_3-N (3.7 kg/ha) and the grass plot lost the most (5.3 kg/ha). The control plot lost 4.9 kg/ha. The greatest loss of NO_3-N occurred in the mid-monsoon from all treatments. The losses were similar in the early- and late- monsoon periods from intervention plots. The loss from the control was higher in the early-monsoon than from the late-monsoon. There were no significant differences between the cropping systems ($P = 0.95$) or between the treatments ($P = 0.85$) for K content in runoff (Fig. 5.9 b). The total loss of K in runoff was found to be slightly higher (6.9 kg/ha) from the maize/barley cropping system than from the maize/finger millet cropping system (6.5 kg/ha). Both closed and grass plots lost less K (5.3 - 5.9 kg/ha) in runoff than the control plot (8.8 kg/ha). These plots lost more K in the early-monsoon and the loss decreased through to the late-monsoon. In the control the highest loss was observed in the mid-monsoon and the lowest loss in the late-monsoon. The differences between the mean of interventions and control and between the two interventions were insignificant ($P \geq 0.24$) for N and K content in runoff.

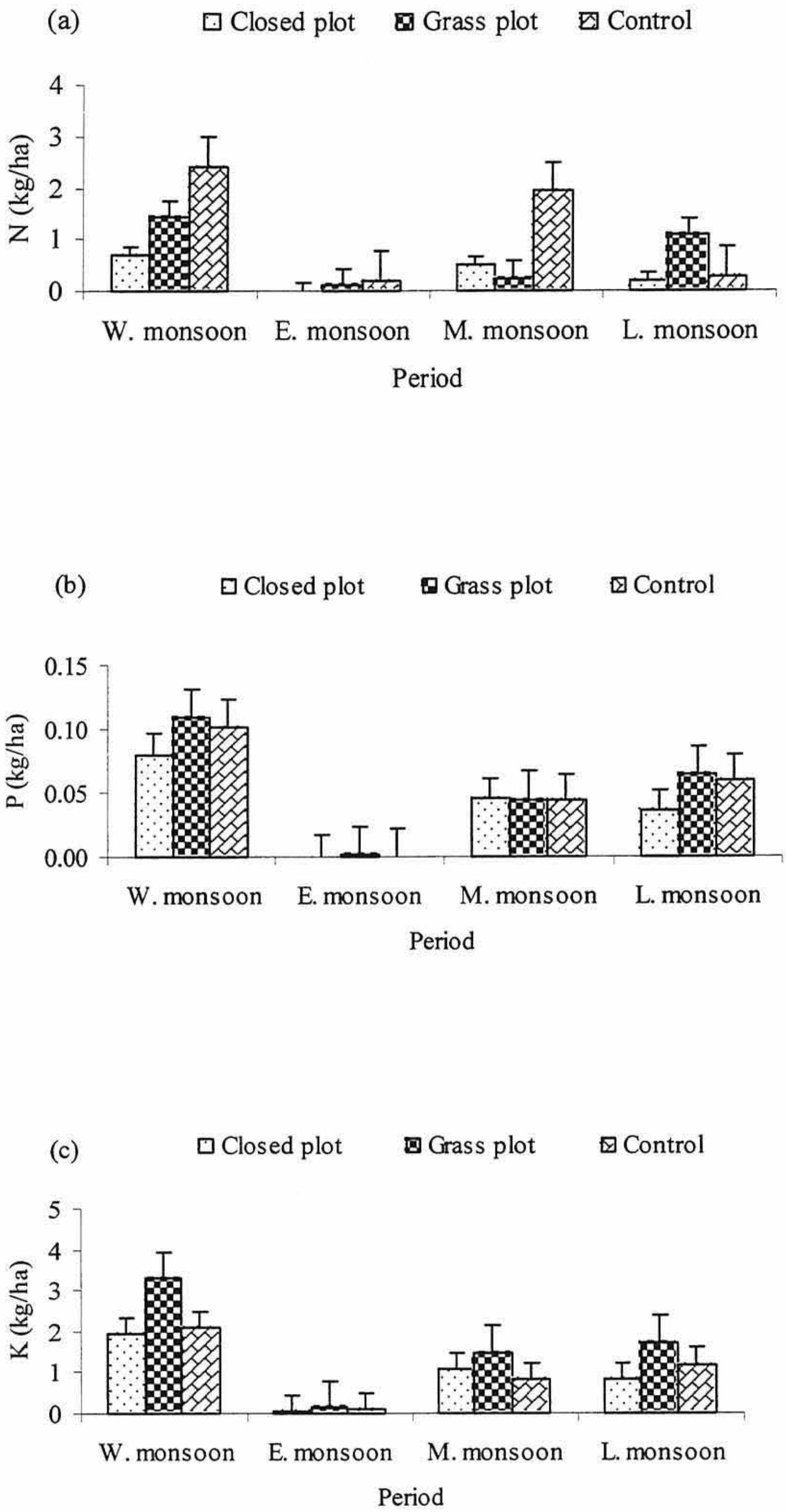


Fig. 5. 7 Nutrient loss in runoff (a) NO_3-N, (b) P and (c) K (Landruk, 2000).

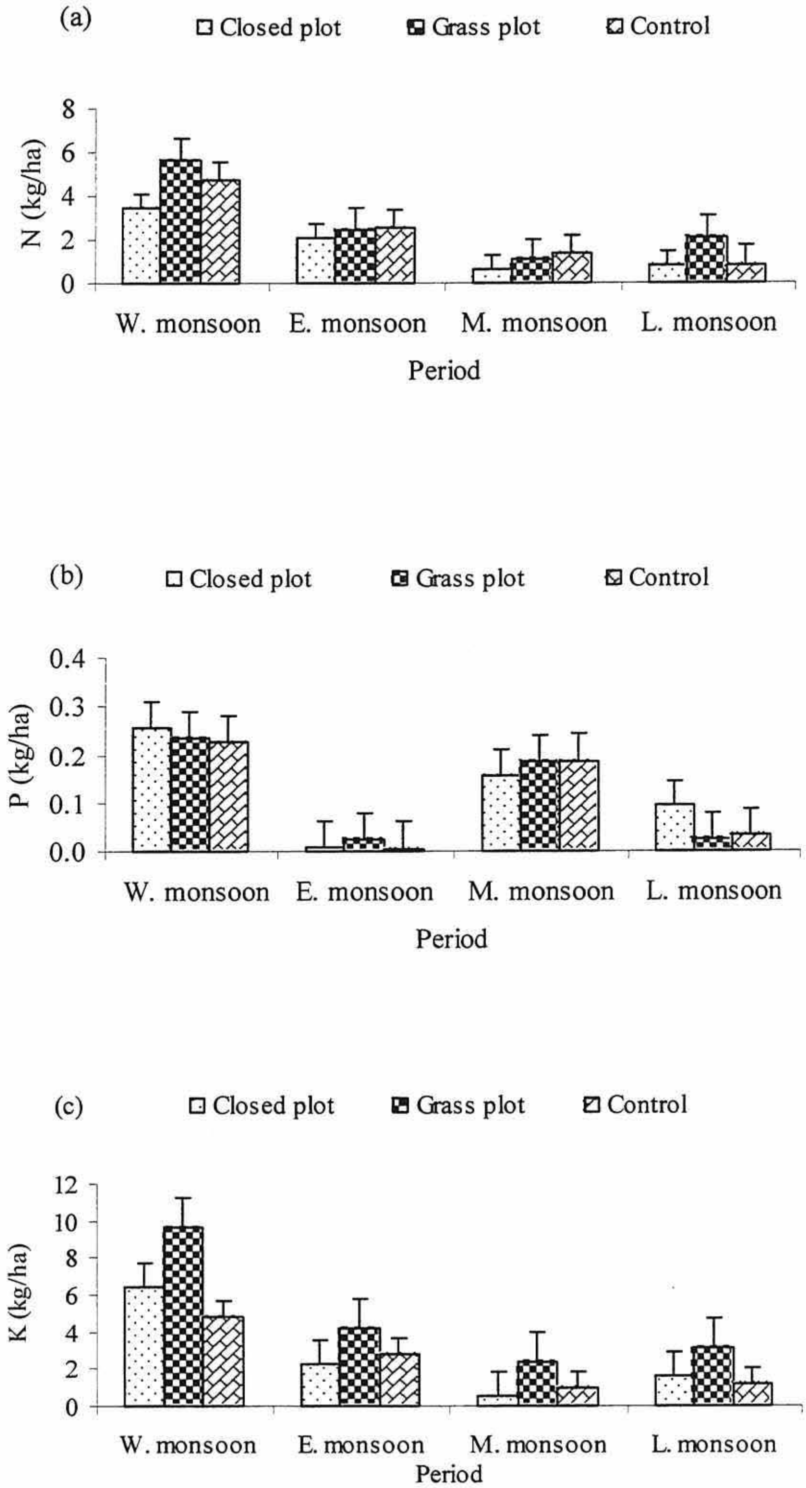


Fig. 5.8 Nutrient loss in runoff (a) NO_3-N, (b) P and (c) K (Landruk, 2001).

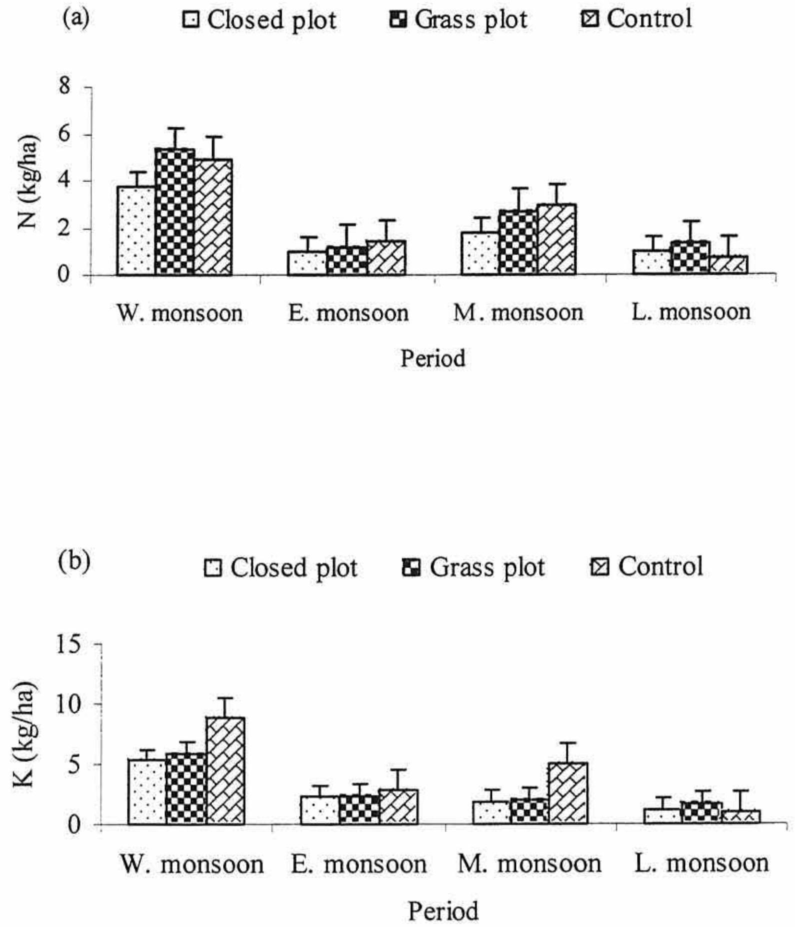


Fig. 5.9 Nutrient loss in runoff (a) NO_3-N and (b) K (Landruk, 2002).

5.3.5 Sediment nutrients

Eroded sediments were analysed for organic carbon, total nitrogen, available phosphorus and exchangeable potassium in the year 2000 (Table 5.2). The concentration of organic carbon was highest (48.3 g/kg) in the closed plot followed by 43.0 g/kg in the grass plot. The least concentration of organic carbon was found in the sediment from the control plot (41.8 g/kg). There were no significant differences in organic carbon content between the treatments.

There was no significant difference in total nitrogen content between the treatments. However, there was a significant difference in the concentration of available P in sediment between the treatments. The closed plot sediment had the highest P concentration (139 mg/kg). The control plot sediment had the lowest P concentration (70.1 mg/kg). Sediment from the grass plot had a P concentration of 98.0 mg/kg. There was no significant difference in the concentration of exchangeable K in eroded sediment between the treatments. The lowest concentration of K was 101.0 mg/kg in sediment from the grass plot and the highest concentration (124.5 mg/kg) was in sediment from the control plot.

The organic carbon and available P contents were much higher in the eroded sediment than the bench mark soil. There was a small difference in P between eroded sediment from the control and bench mark soil. In contrast, the exchangeable K and total N were higher in the bench mark soil than in eroded sediment from all treatment plots.

The differences between the mean of interventions and control and between the two interventions for organic carbon content, total N content and K content in sediments were insignificant ($P = > 0.16$). however, the differences between the mean of interventions and control and between the two interventions for P content in the sediment were significant ($P = 0.03$ and $P = 0.08$).

In 2001 eroded sediment was analysed for organic carbon, total N, available P and exchangeable K and there were no significant differences ($P = \geq 0.47$) between the treatments (Table 5.3). Organic carbon was highest (78.6 g/kg) in sediment from the control plot and lowest in sediment from the grass plot (69.9 g/kg). There was no significant difference in total N between the treatments. Total N was highest (3.1 g/kg) in the closed plot and lowest (2.9 g/kg) in the control plot. There was no significant difference in available P between the treatments, values only ranging from 123.3 to 125.5 mg/kg. There was no significant difference in K between the treatments. It was highest (213.0 mg/kg) in the sediment collected from the closed plot and lowest (174.0 mg/kg) in the sediment collected from the grass plot. Concentrations of organic carbon, total N, available P and exchangeable K were higher in eroded sediment from all treatments compared with the bench mark soil sample. The differences between the mean of interventions and control and between the two interventions were insignificant for organic carbon, total N, available P and for exchangeable K content in the sediment ($P \geq 0.41$).

In 2002, as in previous years, sediments were collected from the different treatment plots and were analysed for organic carbon, total N, available P and exchangeable K contents (Table 5.4). Organic carbon content in sediments was found to be significantly different between the two cropping systems (P = 0.02). Eroded sediment from the maize/millet system had a higher organic carbon content (27.0 g/kg) than the sediment collected from the maize/barley cropping system (15.3 g/kg). Organic carbon contents from the treatment plots also differed significantly (P = 0.07). The sediment from intervention plots had less organic carbon (21.1-22.8 g/kg) than the sediment collected from the control plot (30.2 g/kg). There was a significant difference in total N content in the sediment between the two cropping systems. (P = 0.09). Sediment collected from the maize/millet cropping system had a higher N content (3.1 g/kg) compared with 2.1 g/kg in the sediment collected from the maize/barley cropping system. The lowest N content (2.5 g/kg) was from the closed plot and the highest (3.2 g/kg) was from the grass plot. Sediment from the control plot contained 3.0 g/kg. However, differences between treatments were insignificant (P = 0.84). Available P was significantly different between the two cropping systems (P = 0.15). P was found to be higher in sediment from the maize/millet cropping system (48.0 mg/kg) than in the sediment from the maize/barley cropping system (45.0 mg/kg). There was no significant difference in P content in the sediments from different treatment plots (P = 0.23). P content was higher in sediments from grass plot (48.2 mg/kg) and control plot (47.3 mg/kg) than in sediment from the closed plot (46.7 mg/kg). The two cropping systems were significantly different in terms of exchangeable K content (P = 0.01). K content was higher (231.4 mg/kg) in the sediment from the maize/millet cropping system than from the maize/barley cropping system (80.8 mg/kg). K content in the sediment was not significantly different between the treatments (P = 0.84). K content was 204.2 mg/kg in both the control and closed plots and lowest (195.1 mg/kg) in the grass plot. The differences between the mean of interventions and control and between the two interventions were insignificant ($P \geq 0.45$) for organic carbon, total N, available P and exchangeable K content in the sediments. However, there was a significant difference between the mean of the interventions and the control (P = 0.04) for organic carbon and between the two interventions (P = 0.12) for total N.

Table 5.2 Effect of cropping systems and treatments on the nutrient element contents of eroded sediment (Landruk, 2000).				
Factors	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	Exch. K (mg/kg)
Cropping system				
Maize/millet	46.0	2.3	98.9	123.1
Maize-wheat/barley	35.3	1.8	115.8	76.8
SED	**4.79**	**0.33**	**29.15**	**15.19**
Treatment				
Closed plot	48.3	2.2	139.1	116.3
Grass plot (grass planted in risers)	43.0	2.1	97.7	101.0
Control (Farmers' Practice)	41.8	2.2	70.1	124.5
Mean	**44.4**	**2.18**	**102.3**	**113.9**
SED	**3.71**	**0.26**	**22.58**	**11.77**

Table 5.3 Effect of cropping systems and treatments on the nutrient element contents of eroded sediment (Landruk, 2001)				
Factors	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	Exch. K (mg/kg)
Cropping system				
Maize/millet	61.3	2.7	85.4	66.0
Maize-wheat/barley	77.2	3.0	134.0	226.0
SED	**8.53**	**0.68**	**14.78**	**57.1**
Treatment				
Closed plot	73.6	3.1	124.1	213.0
Grass plot	69.9	2.8	123.3	174.0
Control (Farmers' Practice)	78.6	2.9	125.5	195.0
Mean	**74.0**	**2.93**	**124.3**	**194.0**
SED	**6.60**	**0.52**	**11.45**	**44.30**

Table 5.4 Effect of cropping systems and treatments on the nutrient element contents of eroded sediment (Landruk, 2002)				
Factors	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	Exch. K (mg/kg)
Cropping system				
Maize/millet	27.0	3.1	47.99	231.2
Maize-wheat/barley	15.3	2.1	44.89	80.8
SED	**3.71**	**0.48**	**1.87**	**24.05**
Treatment				
Closed plot	22.8	2.5	46.7	204.2
Grass plot	21.1	3.2	48.2	195.1
Control (Farmers' Practice)	30.2	3.0	47.3	204.2
Mean	**24.7**	**2.88**	**47.4**	**201.1**
SED	**2.87**	**0.37**	**1.45**	**18.63**

5.3.6 Leachate

62 % of rainfall was lost as leachate from the closed plot, 49.9 % from the control plot and 40.2 % from the grass plot (Fig. 5.10 a) in 2000. The percentage of rainfall lost as leachate was lower in the early-monsoon than in the mid-monsoon and late-monsoon periods. There was no significant difference in the amount of leachate between the treatments (Fig. 5.11 a). Total leachate was highest (1984 mm) in the closed plot and lowest (1282 mm) in the grass plot. Leachate amount was highest from the closed plot in each monsoon period and lowest from the grass plot throughout the monsoon periods. The contrast between the mean of interventions and control and between the two interventions was insignificant ($P \geq 0.29$).

52.8 % of rainfall was lost as leachate from the closed plot, 33.3 % from the plot of grass planted in terrace risers and 43.0 % from the control plot (Fig. 5.10 b) in 2001. The leachate (%) was lower in the early-monsoon than in the mid-monsoon and late-monsoon. There was no significant difference in the amount of leachate between the treatments ($P = 0.49$) [Fig. 5.11 b]. Total leachate was highest (1948 mm) in the closed plot, 1588 mm in the control plot and lowest (1230 mm) in the grass plot. More leachate was lost from the closed plot and from the control plot than from the grass plot in the mid-monsoon and late-monsoon periods. The control plot produced higher leachate than the closed plot in the early-monsoon. The contrast between intervention and control as well as between the two interventions was insignificant ($P \geq 0.30$).

26.2 % of rainfall was lost as leachate from the closed plot, 18.0 % from the plot of grass planted in terrace risers and 21.3 % from the control plot (Fig.5.10 c) in 2002. The amount of leachate was found to be insignificantly different between the two cropping systems ($P = 0.12$). The maize/millet cropping system had higher leachate (1228.5 mm) than the maize/barley cropping system (274.0 mm). There was no significant difference in the amount of leachate between the treatments ($P = 0.86$) [Fig.5.11 c]. The closed plot had the highest leachate (902.7 mm) and the grass plot had the lowest leachate (618.2 mm). The control plot had 732.8 mm leachate. There was no significant difference in early-monsoon leaching between the two cropping systems ($P = 0.44$) or between the treatments ($P = 0.62$). However, the control had the highest leachate (65mm), the closed plot had 45.2mm leachate and the grass plot had the least leachate (only 19.1 mm) during the early-monsoon. Leachate in the mid-monsoon differed significantly between cropping systems ($P = 0.10$) but was not significantly different between the treatments ($P = 0.88$). The maize/millet cropping system gave a higher leachate (692.5 mm) than the maize/barley system (179.0 mm). The closed plot gave the highest leachate (505.3 mm) and the grass plot gave the lowest leachate (373.5 mm). The control gave 426.2 mm leachate. Late-monsoon leachate differed significantly between cropping systems ($P = 0.08$) but did not differ significantly between the treatments ($P = 0.76$). The trend of leachate in different cropping systems and treatments was similar to the trend in the mid-monsoon. The contrast between intervention and control and between the two interventions was insignificant ($P \geq 0.25$).

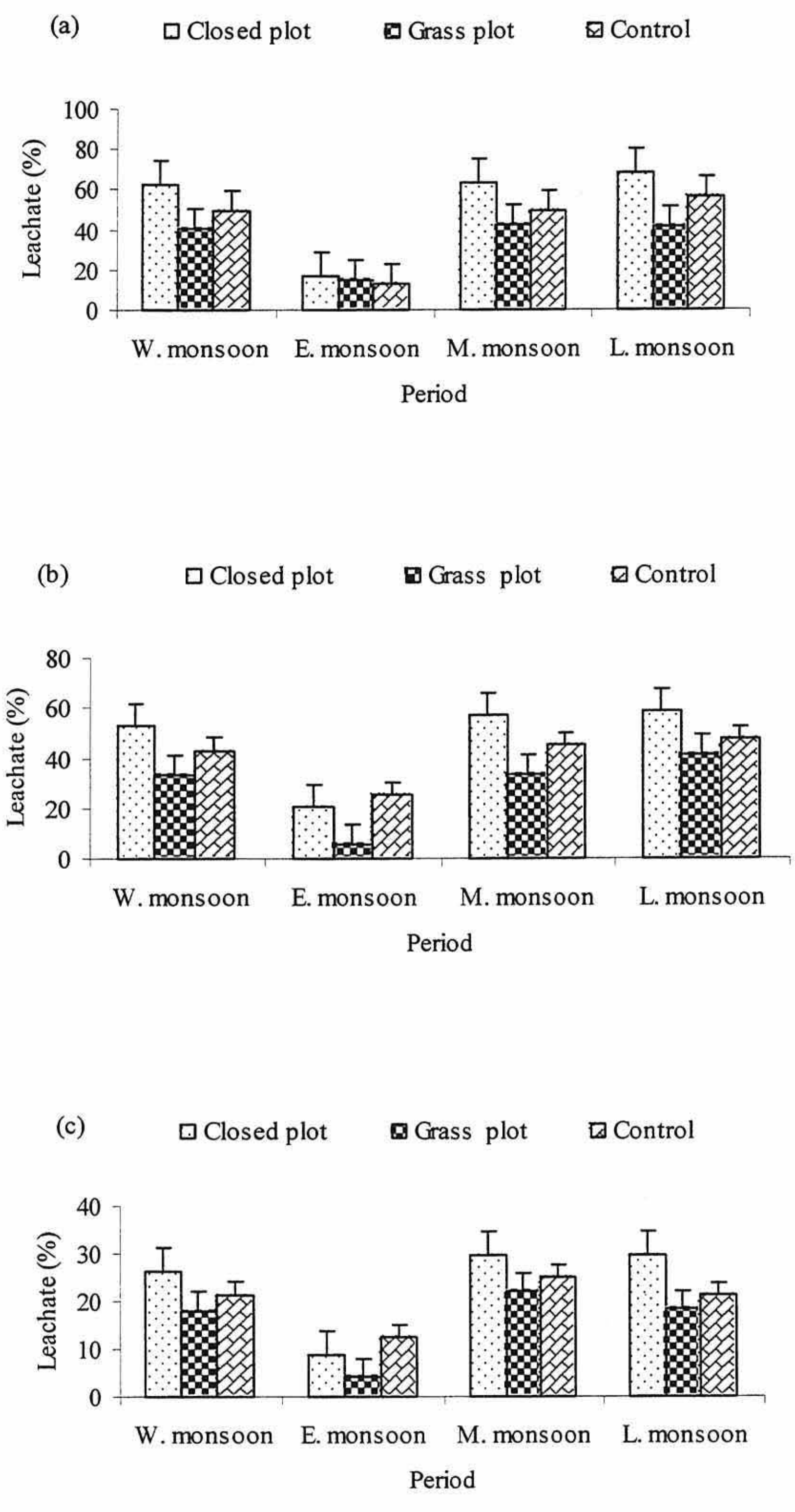


Fig. 5.10 Leachate (percentage of rainfall) during (a) 2000, (b) 2001 and (c) 2002 at Landruk.

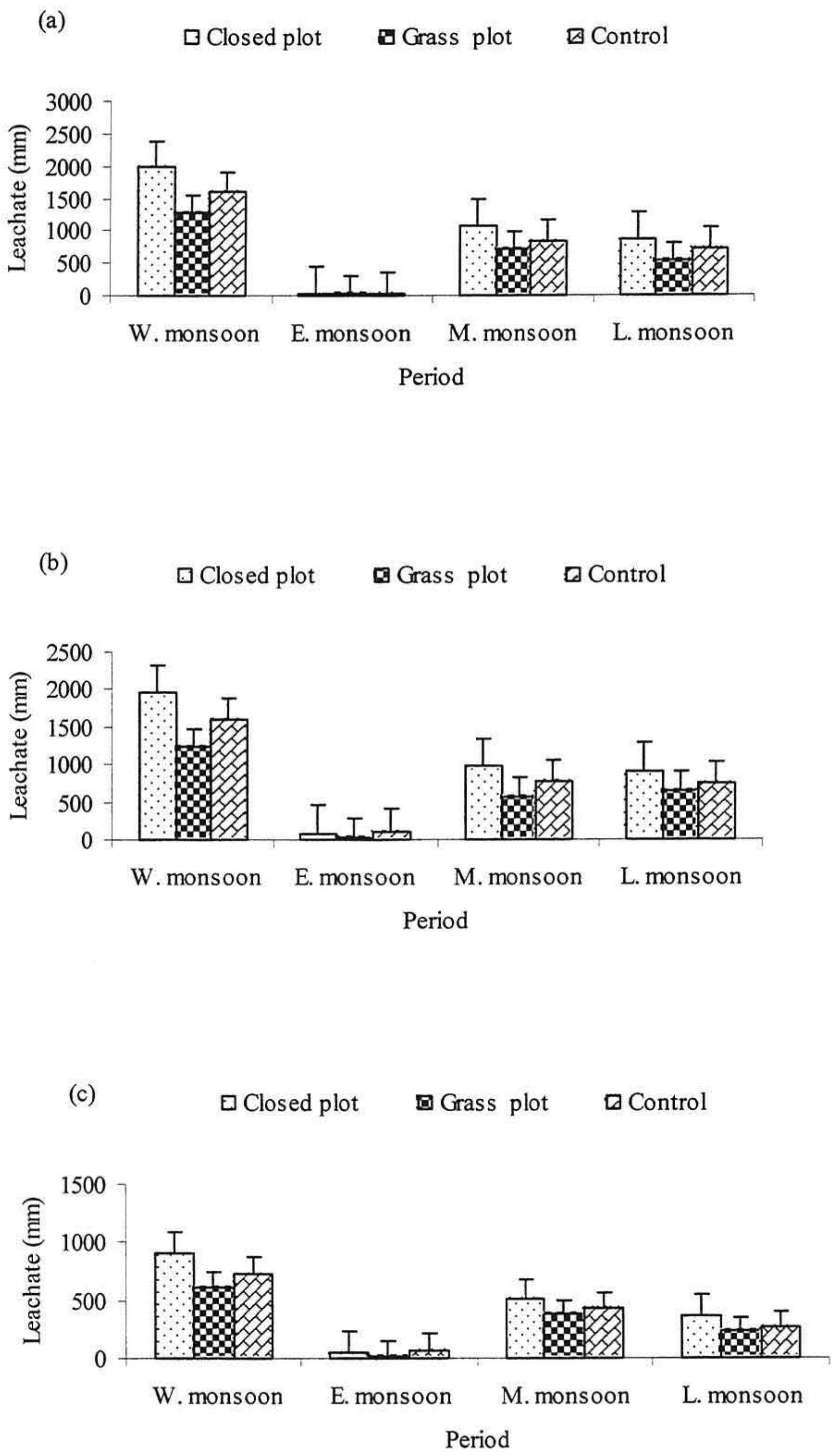


Fig. 5.11 Leachate amount (mm) during (a) 2000, (b) 2001 and (c) 2002 at Landruk.

5.3.7 Nutrients in leachate

In 2000 there was no significant difference in total NO_3-N in leachate between the treatments (P = 0.45) [Fig. 5.12 a]. 97.9 kg/ha was leached from the closed plot and 73.4 kg/ha was leached from the control plot. The loss of NO_3-N in leachate was 95.4 kg/ha from the grass plot. More NO_3-N was leached from the closed plot than from the grass plot in the early- and late-monsoon periods. However, there was more leaching from the grass plot than from the control plot during the mid-monsoon period. More N was leached during the mid-monsoon in all treatment plots.

Leaching of P did not significantly differ between the treatments (P = 0.18). Its loss was higher from the control plot than from both the intervention plots (Fig 5.12 b). Maximum leaching of P was 0.9 kg/ha. More P was leached during the mid-monsoon period.

Leaching of K did not significantly differ between the treatments (P = 0.87) [Fig. 5.12 c]. The highest K leaching was from the closed plot (99.2 kg/ha) and the lowest was from the grass plot (61.1 kg/ha). More K was leached during the mid-monsoon than during the early-monsoon period from all treatment plots.

The contrast between intervention and control was not significant for N and K leaching ($P \geq 0.33$) but was significant for P leaching (P = 0.08). The contrast between the two interventions was also insignificant for N, P and K leaching ($P \geq 0.36$).

In 2001 there was no significant difference in the leaching of total NO_3-N between the treatments (P = 0.59) [Fig. 5.13 a]. Its loss in leachate was highest from the closed plot (99.7 kg/ha) and lowest from the control plot (61.3 kg/ha). The loss of NO_3 -N from the grass plot was similar (61.6 kg/ha) to the loss from the control plot. NO_3 -N leaching was higher during the mid-monsoon and lower in the early-monsoon than in the late-monsoon from all the treatment plots except from the control plot. In the latter its leaching was slightly greater in the early-monsoon than in the late-monsoon.

There was no significant difference in the leaching of P between the treatments (P = 0.99) [Fig 5.13 b]. Its loss in leachate was highest from the closed plot and least from the control plot. However, none of the treatments exceeded a loss of 0.26 kg/ha over the whole monsoon period.

There was no significant difference in leaching of K between the treatments ($P = 0.78$). Its loss in leachate was highest (59.4 kg/ha) from the closed plot, 48.0 kg/ha from the control plot and least (34.9 kg/ha) from grass plot (Fig. 5.13 c). Its leaching was higher from the control plot in the early-monsoon and slightly higher from the control compared with other treatment plots in the mid-monsoon. The leaching of K from the grass plot remained lower than the control throughout the whole monsoon period. K leaching was higher in the mid-monsoon from all treatment plots except from the closed plot. The latter experienced more K leaching in the late-monsoon.

The contrast between intervention and control was insignificant ($P \geq 0.56$) for N, P and K leaching. The contrast between the two interventions was also insignificant ($P \geq 0.33$).

In 2002 leachate was analysed for NO_3 -N and K. The loss of N was significantly different ($P = 0.06$) between the two cropping systems. The loss of N was higher from the maize/millet system (32.7 kg/ha) than from the maize/barley system (10 kg/ha). There was no significant difference in the loss of NO_3 -N ($P = 0.45$) between the treatments (Fig. 5.14 a). Intervention plots lost more NO_3 -N (18.3 - 28.6 kg/ha) than the control plot (17.3 kg/ha). The closed plot lost more N than the grass plot. The loss of NO_3 -N was greater in the mid-monsoon and less in the early-monsoon from all treatments except in the case of the control. This lost slightly more in the early-monsoon than in the late-monsoon. The contrast between intervention and control and between the two interventions for NO_3 -N loss was insignificant ($P \geq 0.23$).

Loss of K in leachate did not differ significantly between the two cropping systems or between the treatments ($P \geq 0.90$) [Fig 5.14 b]. 31.4 kg K/ha was lost from the maize/millet system and 30.4 kg/ha from the maize/barley cropping system. The closed plot lost more K (35.3 kg/ha) than the grass plot (26.7 kg/ha). The control plot lost 30.7 kg/ha. There were no significant differences in the loss of K ($P \geq 0.61$) between treatments in any period of the monsoon. K loss in leachate was highest in the mid-monsoon and lowest in the early-monsoon from all treatments. The contrast between the intervention and the control and between the two interventions was insignificant ($P \geq 0.29$).

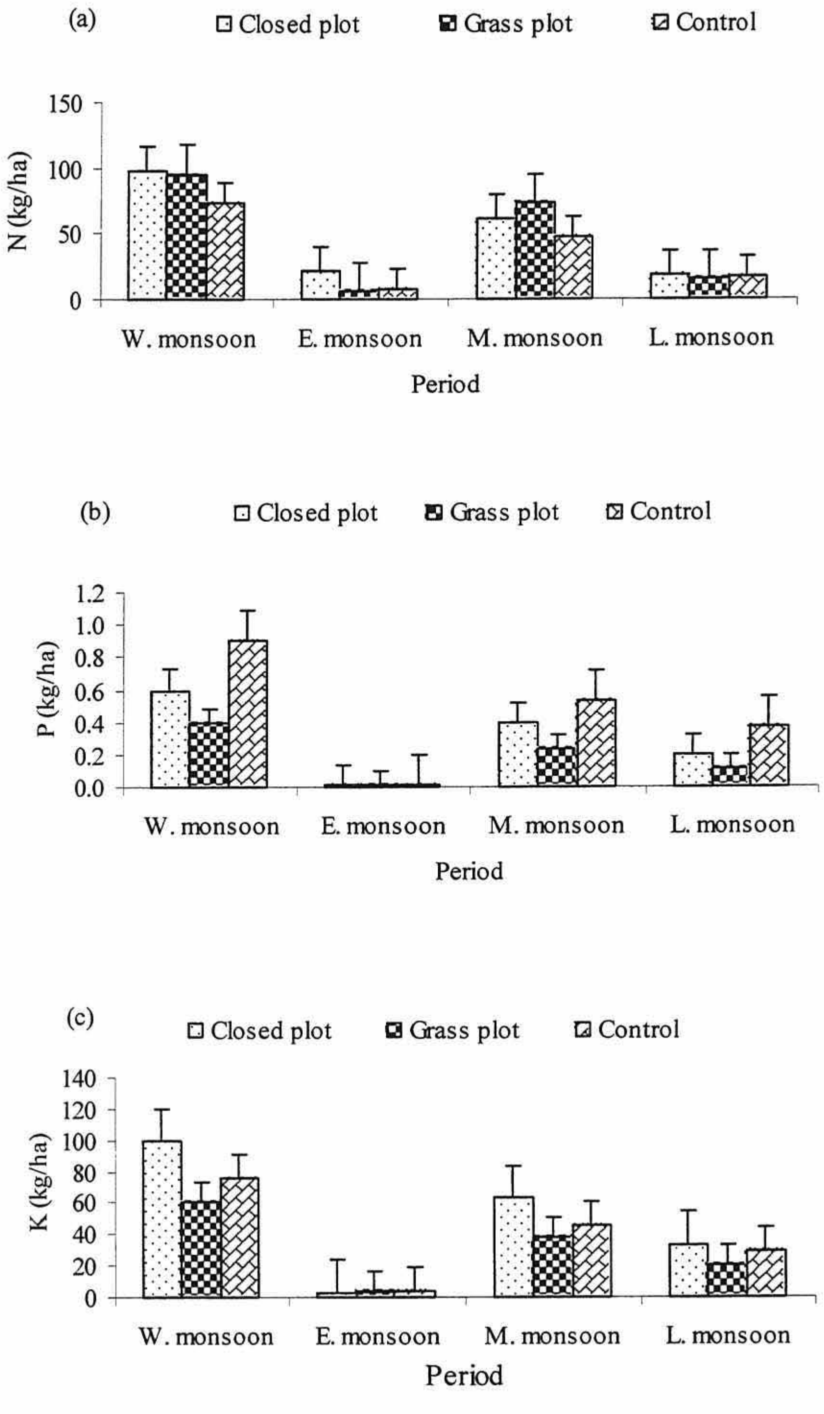


Fig. 5.12 Nutrients in leachate (a) NO_3-N, (b) P and (c) K (Landruk, 2000).

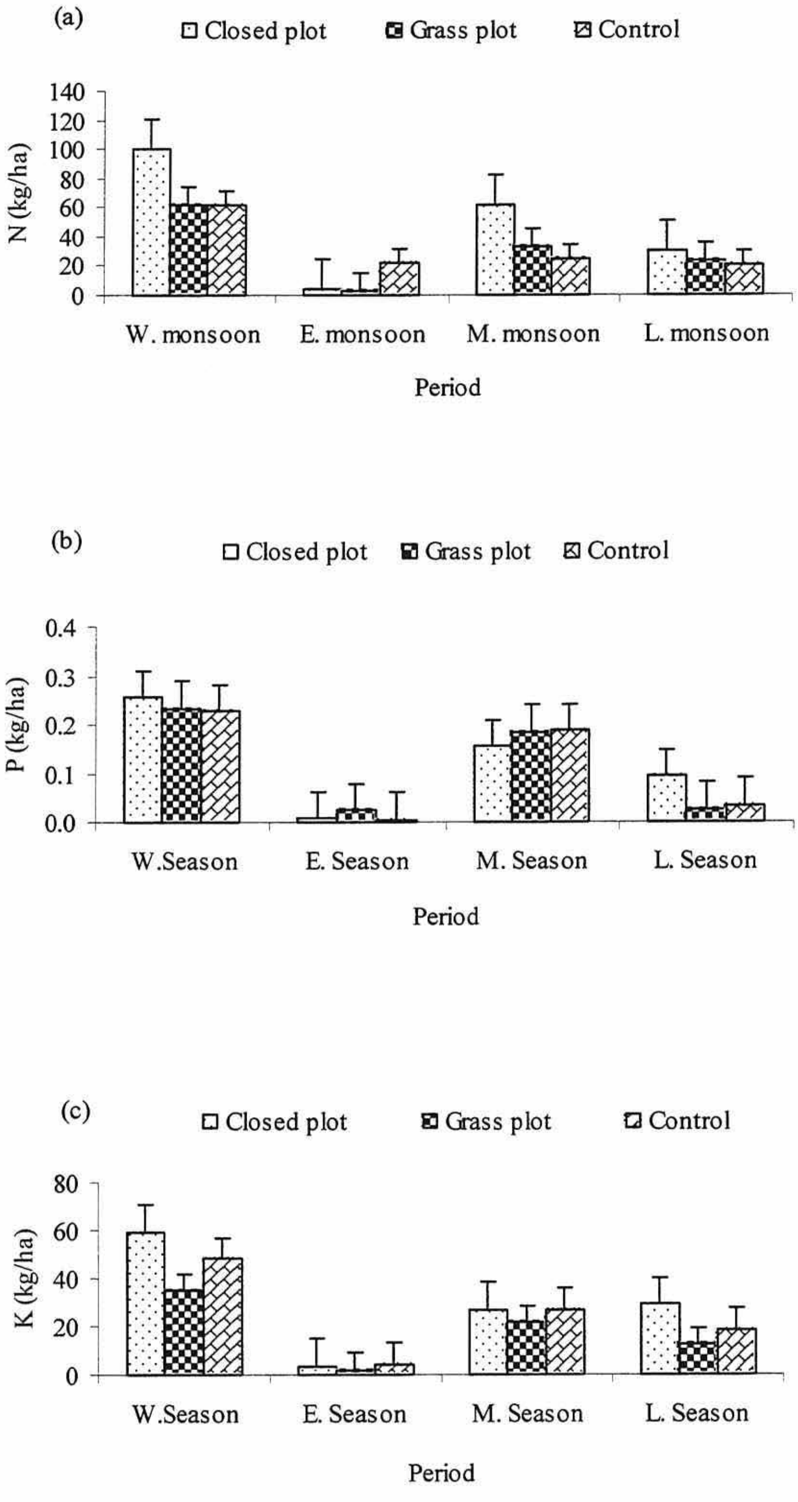
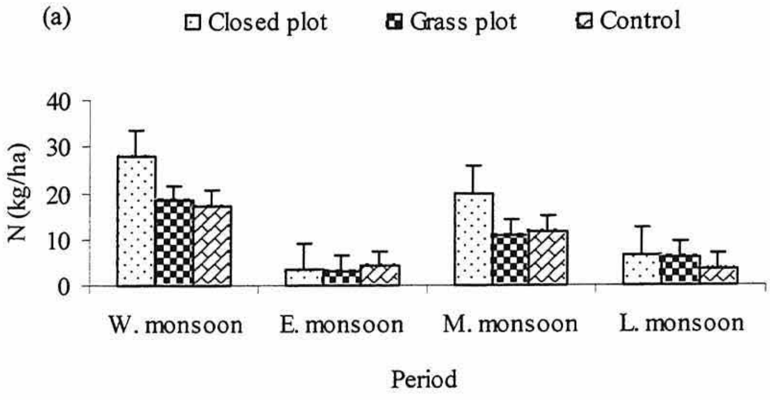


Fig. 5.13 Nutrients in leachate (a) NO_3-N, (b) P and (c) K (Landruk, 2001).



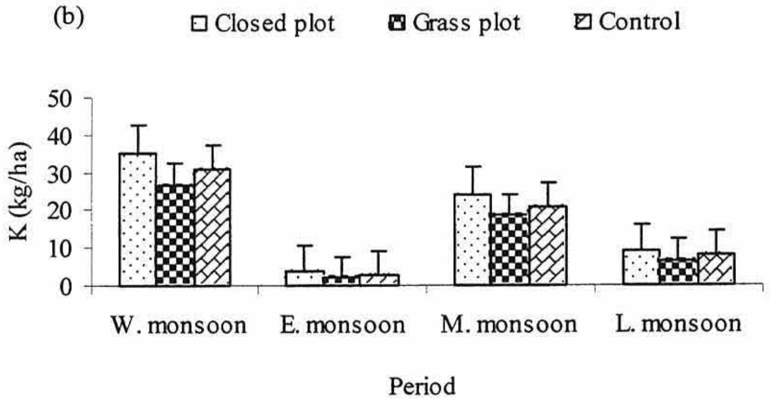
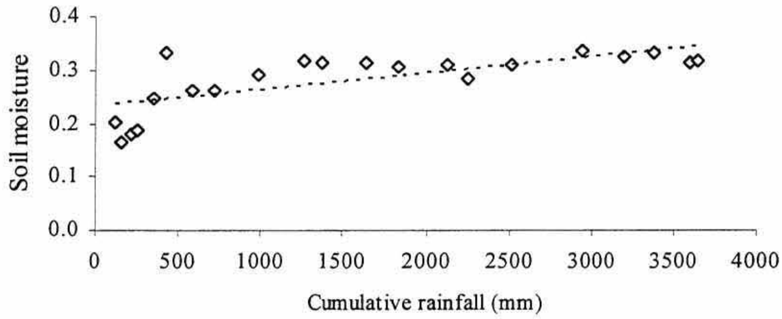


Fig. 5.14 Nutrients in leachate (a) NO_3-N and (b) K (Landruk, 2002).

5.3.8 Soil moisture

There was no significant difference in soil moisture content between the treatments in the years 2001 and 2002 ($P \geq 0.30$). However, soil moisture content was highest in the closed plot (0.36 m^3/m^3) and lowest in the control (0.34 m^3/m^3) in 2001. It was similar in the intervention and control plots (0.23 - 0.24 m^3/m^3) in 2002. Soil moisture content was plotted against cumulative rainfall for the control and intervention plots (Figs.5.15 - 5.16). There was more variation in soil moisture content (ranging from 0.16 m^3/m^3 to 0.33 m^3/m^3) in the control plot compared with the intervention plot (ranging from 0.18- 0.28 m^3/m^3) when the cumulative rainfall was below 500 mm in 2001. After this soil moisture content remained fairly constant between 0.26 m^3/m^3 and 0.33 m^3/m^3 in the control plot and between 0.28m^3/m^3 and 0.35 m^3/m^3 in the intervention plot. The trend lines showed a linear increase in soil moisture content with an increase in cumulative rainfall in both years. There was no distinct relationship between soil moisture content and cumulative rainfall in the intervention or control.

(a)



(b)

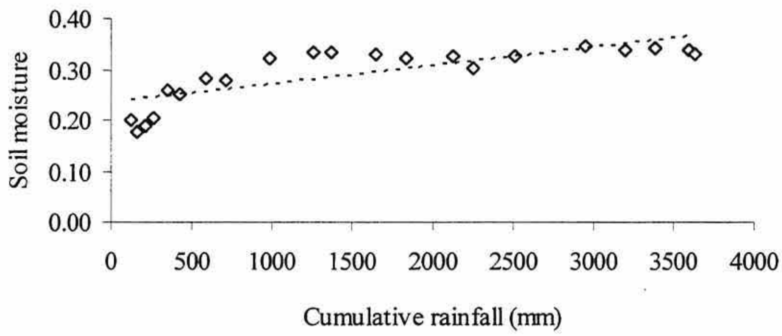


Fig. 5.15 Relationship between soil moisture content (m^3/m^3) and cumulative rainfall (a) control and (b) intervention (Landruk, 2001).

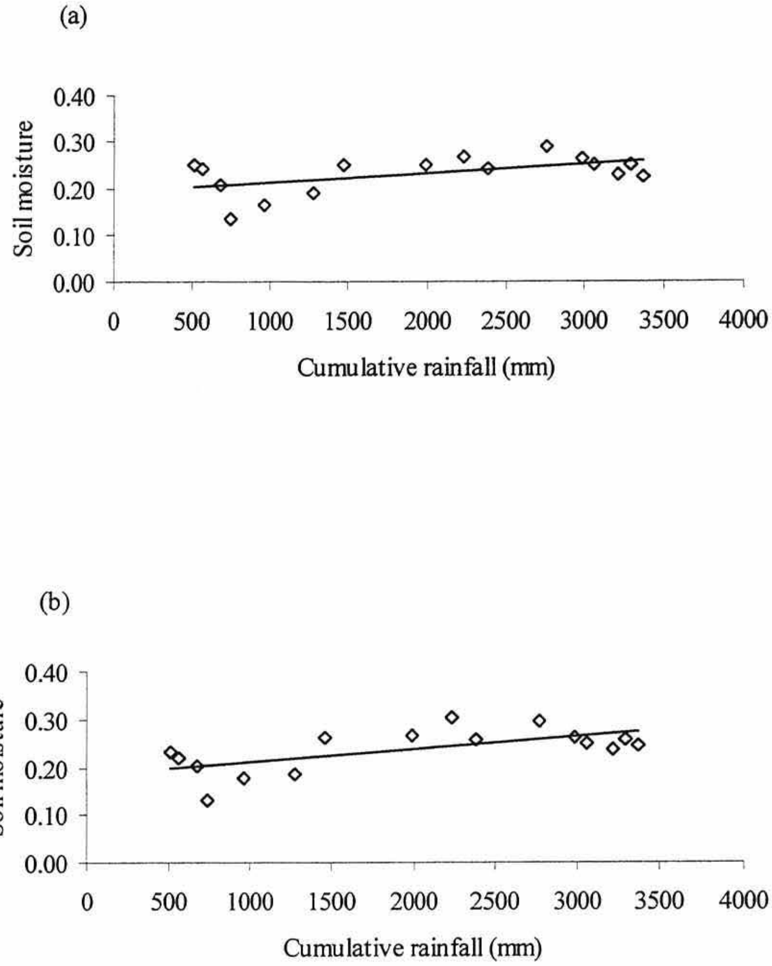


Fig. 5.16 Relationship between soil moisture content (m^3/m^3) and cumulative rainfall (a) control and (b) intervention (Landruk, 2002).

5.3.9 Soil fertility status

Soil samples were collected following the monsoon season and after completion of the crop cycle each year. They were analysed in the laboratory to determine their pH and organic carbon, total N, available P and exchangeable K content. Additional analysis for CEC and soil particle size distribution (soil texture) was performed during 2002 in order to make a comparison with bench mark values.

pH

Table 5.5 shows the effect of cropping systems and treatments on soil pH at Landruk. In the first two years the cropping system had no effect on pH. The trend in pH was a decrease from top to bottom positions in all years. The effect of treatments on pH was not consistent in 2000 and 2001. pH was found to be high in the control plot compared with both intervention plots in 2000. Contrast between intervention and control and between interventions was insignificant ($p \geq 0.12$). In 2002 pH was significantly different between the two cropping systems ($p = 0.07$). Maize/millet had a low pH (5.2) and maize/barley had a comparatively high pH (6.0). The difference in pH was significant ($P = 0.01$) between the treatments. Intervention decreased pH compared with the initial value (5.4) but pH was not affected in the control. pH differed significantly between plot positions ($P = 0.07$). The top of the plot was not affected and had a similar pH to the bench mark value. The middle and bottom positions had a lower pH. Contrast between intervention and control and between the two interventions was insignificant ($P \geq 0.25$)

Table 5.5 Effect of cropping systems and treatment on soil pH (Landruk).

Factors	2000	2001	2002
Cropping system			
Maize/millet	5.5	6.7	5.2
Maize/barley	6.9	5.4	6.0
SED	-	-	-
Treatment			
Closed plot	5.7	5.6	5.3
Grass plot	5.8	5.7	5.3
Control (Farmers' practice)	5.9	5.6	5.4
SED	**0.08**	**0.12**	**0.05**
Plot position			
Top	6.2	5.7	5.4
Middle	5.7	5.7	5.3
Bottom	5.5	5.6	5.3
Mean	**5.8**	**5.7**	**5.3**
SED	**0.25**	**0.07**	**0.02**

Organic carbon

Table 5.6 shows the effect of cropping systems and treatments on soil organic carbon content at Landruk. Cropping system and plot position had no significant effect on organic carbon in the first two years. In 2000 soil organic matter content was highest in the closed plot and lowest in the control plot. However, soil organic carbon content was significantly higher (P = 0.05) in the control in 2001. Contrast between intervention and control was significant (P = 0.09). There was no significant difference between the two interventions in either year. In 2002 soil organic carbon content was not significantly different between the two cropping systems or between the treatments ($P \geq 0.57$). However, soil organic carbon content was higher in the maize/millet system (14.8 g/kg) and lower in the maize/barley system (6.9 g/kg). The range of organic carbon content in the treatments was 13.0 to 13.5 g/kg, the closed plot having the least and the grass plot having the highest content. There was a significant difference between plot positions for organic carbon content (P = 0.07). It was 12.4 g/kg at the top and 13.7 g/kg at the bottom. The organic carbon in the soil decreased irrespective of the cropping system, treatment and plot position compared with the initial value of 16.7 g/kg soil. Contrast between intervention and control and between the two interventions was insignificant ($P \geq 0.79$).

Table 5.6 Effect of cropping systems and treatment on organic carbon (g/kg) in soil (Landruk)

Factors	2000	2001	2002
Cropping system			
Maize/millet	17.8	4.2	14.8
Maize/barley	8.1	14.2	6.9
SED	-	-	-
Treatment			
Closed plot	17.7	11.8	13.0
Grass plot	16.3	11.1	13.5
Control (Farmers' practice)	13.5	13.6	13.4
SED	**1.2**	**1.1**	**2.1**
Plot position			
Top	17.5	11.9	12.4
Middle	15.3	12.4	13.7
Bottom	14.7	12.3	13.7
Mean	**15.8**	**12.2**	**13.3**
SED	**2.60**	**0.53**	**0.90**

Total N

Table 5.7 shows the effect of cropping systems and treatments on soil N content at Landruk. Cropping system, plot position and treatment had no significant effect on total N in soil ($P \geq 0.19$) in any year (2000, 2001 and 2002). However, a significant difference between treatments was seen in 2002 (P = 0.01). The maize/millet system had a lower N content than the maize/barley system throughout the testing seasons. In 2002 the closed plot contained more N (1.6 g/kg) and the grass plot contained less N (1.1 g/kg) than the control (1.4 g/kg). N content was lower at the top than in the middle and bottom positions. Total soil N content was lower in all treatments than the bench mark value. There was no significant difference in total N between intervention and control ($P \geq 0.28$) in any year. There was a significant difference ($P = 0.01$) between the two interventions in 2002. This indicated that the closed plot lost less N than the grass plot even after the establishment of grass roots in risers.

Table 5.7 Effect of cropping systems and treatment on total N (g/kg) in soil (Landruk).

Factors	2000	2001	2002
Cropping system			
Maize/millet	1.1	0.7	1.3
Maize/barley	1.6	1.0	1.4
SED	-	-	-
Treatment			
Closed plot	1.0	0.97	1.6
Grass plot	1.3	0.87	1.1
Control (Farmers' practice)	1.3	0.92	1.4
SED	**0.21**	**0.08**	**0.07**
Plot position			
Top	1.2	0.97	1.3
Middle	1.2	0.88	1.4
Bottom	1.2	0.91	1.4
Mean	**1.2**	**0.9**	**1.3**
SED	**0.5**	**0.1**	**0.1**

Available P

Table 5.8 shows the effect of cropping systems and treatments on available P in soil at Landruk. In the first two years there was no significant difference in available P between the cropping systems or plot positions ($P \geq 0.37$). However, in 2001 there was a significant difference between treatments ($P = 0.03$). The highest available P content was in soil from the grass plot (50.8 mg/kg) compared with the control plot (46.3 mg/kg). In 2002 available P in the soil was not significantly different between the two cropping systems ($P = 0.16$). However, the maize/millet cropping system had soil containing a higher P content (35.0 mg/kg) than the soil in the maize/barley system (26.0 mg/kg). Similarly, there was no significant difference in P content between treatments ($P = 0.26$). The closed plot had less P (31.9 mg/kg) and the grass plot had more P (34.1 mg/kg) than the control plot (33.5 mg/kg). P content did not vary significantly ($P = 0.28$) between plot positions. The top position had a higher P content (34.1 mg/kg) than the middle position (32.2 mg/kg). P content was lower in all cropping systems, treatments and plot positions compared with the initial value (56.5 mg/kg). There was no significant difference in P content between intervention and control or between the two interventions ($P \geq 0.20$) in any year.

Table 5.8 Effect of cropping systems and treatments on available P (mg/kg) in soil (Landruk).

Factors	2000	2001	2002
Cropping system			
Maize/millet	52.2	43.2	35.0
Maize/barley	47.9	49.1	26.0
SED	-	-	-
Treatment			
Closed plot	55.1	46.6	31.9
Grass plot	48.3	50.8	34.1
Control (Farmers' practice)	50.6	46.3	33.5
SED	**5.5**	**2.5**	**1.6**
Plot position			
Top	51.7	48.1	34.1
Middle	51.9	47.3	32.2
Bottom	50.4	48.3	33.3
Mean	**51.3**	**47.9**	**33.2**
SED	**1.2**	**0.7**	**1.3**

Exchangeable K

Table 5.9 shows the effect of cropping systems and treatments on exchangeable K in soil at Landruk. Exchangeable K was not significantly different between the two cropping systems over 2000 and 2001 ($p \geq 0.92$). Plot positions showed a significant difference in K content in 2000 ($p = 0.06$) and no significant difference in K content in 2001($P \geq 0.56$). A significant difference between treatments was observed in all years ($P = 0.08$ in 2001 and $P \leq 0.04$ in the other years). Exchangeable K in the soil was highest in the top position and lowest in the bottom position (175.9 - 162.8 mg/kg) in 2000. K content was highest in the control (182.0 mg/kg) in 2000 but was lowest (102.2 mg/kg) in the control in 2001. The contrast between the intervention and control and between the two interventions was insignificant ($P \geq 0.12$). In 2002 there was no significant difference in exchangeable K between the cropping systems ($P = 0.35$). The maize/millet cropping system had a higher K content (112.0 mg/kg) than the maize/barley cropping system (93.8 mg/kg). Treatments were significantly different ($P = 0.01$) for exchangeable K content. Interventions had lower K content (79.7 - 110.5 mg/kg) compared with the control (135.0 mg/kg). Plot positions differed insignificantly in K content ($P = 0.27$). K content declined from the top to bottom positions of the plot (113.7 - 100.7 mg/kg). As with other nutrients, K was also lower in all cropping systems, treatments and plot positions than the bench mark value. The difference between intervention and control and between the two interventions was significant ($P \leq 0.03$). This indicated that K loss could be minimised by interventions, the plot of grass planted in terrace risers giving the best result.

Table 5.9 Effect of cropping systems and treatments on exchangeable K (mg/kg) in soil (Landruk).

Factors	2000	2001	2002
Cropping system			
Maize/millet	164.7	69.9	112.0
Maize/barley	183.1	133.2	93.8
SED	-	-	-
Treatment			
Closed plot	176.9	127.1	110.5
Grass plot	146.3	132.3	79.7
Control (Farmers' practice)	182.0	102.2	135.0
SED	**25.0**	**7.6**	**28.7**
Plot position			
Top	175.9	122.5	113.7
Middle	166.5	121.1	110.8
Bottom	162.8	118.0	100.7
Mean	**168.4**	**120.6**	**108.4**
SED	**6.7**	**4.8**	**8.3**

Cation exchange capacity (CEC)

Table 5.10 shows the effect of cropping systems and treatments on the cation exchange capacity of soil. In 2002 there was no significant difference in the cation exchange capacity of the soil between the cropping systems, between treatments or between plot positions ($P \geq 0.31$). It was lower in the maize/millet system (34.0 meq/100 g) than in the maize/barley system (34.6 meq/100 g). The CEC of soil in both interventions was low (32.0 - 34.7 meq/100 g) compared with the control (35.7 meq/100g). The CEC of soil decreased from bottom (35.3 meq/100g) to top (33.0 meq/100g) positions in the plots. The CEC was lower in all cropping systems, treatments and plot positions compared with the initial value. The contrast between intervention and control and between the two interventions was insignificant ($P \geq 0.20$).

Soil particle size distribution (texture)

Table 5.10 also gives information on soil texture. In 2002 there was a significant difference in sand content between the two cropping systems (P = 0.03). It was higher in the maize/millet system than the maize/barley system. The difference between the treatments was inignificant (P = 0.50). Soil sand particle content was higher in the closed plot and the grass plot (574.2 - 591.0 g/kg) than in the control plot (568.2 g/kg). The difference between plot positions was also insignificant (P = 0.13). However, sand content decreased from the top to bottom positions and was lower than the bench mark value. Contrast between intervention and control and between the two interventions was insignificant (P = 0.32). Soil silt particle content was significantly different between the two cropping systems (P = 0.03). The maize/barley system contained more silt particles than the maize/millet system. There was no significant difference between treatments in silt content (P = 0.41). Both interventions had lower silt contents (363.2 - 377.5 g/kg) than the control (386.2 g/kg). Plot positions were significantly different in terms of silt content (P = 0.05). Silt content decreased from bottom to top positions (383.7 - 369.6 g/kg). The contrast between intervention and control and between the two interventions was insignificant ($P \geq$ 0.23). Silt content was higher in all than the initial value (327.5 g/kg). Clay content in the soil was significantly different between the two cropping systems, the maize/millet system having the highest content (47.0 g/kg) compared with the maize/barley system (45.1 g/kg). There was no significant difference between treatments (P = 0.62). Both intervention plots contained more clay particles (46-48.3 g/kg) than the control (45.6 g/kg). Plot positions showed a significant difference (P = 0.03). The closed plot contained the least clay particles (43.2 g/kg) and the grass plot contained the most (50.0 g/kg) compared with the control (46.7 g/kg). Clay content in the soil was higher in all cases than the bench mark value. The contrast between the intervention and control and between the two interventions was insignificant ($P \geq 0.35$).

Table 5.10 Effect of cropping systems and treatments on cation exchangeable capacity (CEC) of soil (meq/100g) and soil texture (Landruk, 2002).

Factors	CEC (meq/100g)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)
Cropping system				
Maize/millet	34.0	584.0	369.0	47.0
Maize/barley	34.6	552.5	402.4	45.1
SED	-	-	-	-
Treatment				
Closed plot	34.7	591.0	363.2	46.0
Grass plot	32.0	574.2	377.5	48.3
Control (Farmers' practice)	35.7	568.2	386.2	45.6
SED	**5.8**	**8.4**	**6.8**	**2.9**
Plot position				
Top	33.0	583.7	369.6	46.7
Middle	34.0	576.4	373.6	50.0
Bottom	35.3	573.1	383.7	43.2
Mean	**34.1**	**577.7**	**375.6**	**46.6**
SED	**2.4**	**4.1**	**3.8**	**1.3**

5.3.10 Crop yields

Table 5.11 shows that there was no significant difference in grain yield between the two cropping systems (P = 0.38) or between the treatments (P = 0.18) in 2000. However, total crop yield was higher in the maize/millet system (3692 kg/ha) than the maize/barley system (3435 kg/ha). The closed plot produced the highest grain yields (3992 kg/ha) and the control produced the lowest grain yields. Both intervention plots produced higher grain yields than the control. The contrast between the intervention and control was significant (P = 0.08) and between the two interventions it was insignificant (P = 0.38).

In 2001 there was no significant difference in grain yield between the two cropping systems (P = 0.20) or between the treatments (P = 0.76). The maize/millet system gave a higher grain yield (4098 kg/ha) than the maize/barley cropping system (3135 kg/ha). The control plot produced a lower grain yield (3171kg/ha) than the closed plot (3315 kg/ha) and the grass plot (3497 kg/ha). The contrast between intervention and control and between the two interventions was insignificant ($P \geq 0.41$).

In 2002 there was no significant difference between the two cropping systems for grain yield ($P = 0.29$). The grain yield was 5317 kg/ha from the maize/millet system and 4150 kg/ha from the maize/barley cropping system. Grain yields were not significantly different between the treatments ($P = 0.76$). Both interventions produced higher grain yields (5135 - 5640 kg/ha) than the control (4476 kg/ha). The contrast between intervention and control and between the two interventions was insignificant ($P \geq 0.23$).

Table 5.12 indicates that total straw yield in 2000 was significantly different between the two cropping systems ($P = 0.01$). The maize/barley system produced a higher straw yield (18280 kg/ha) than the maize/millet system (13044 kg/ha). This suggests that there was higher biomass production in the maize/barley cropping system. The treatments also produced significantly different straw yields. The closed plot produced the highest straw yield (15418 kg/ha) and the control plot the lowest (13120 kg/ha).

In 2001 the straw yields were significantly different between the cropping systems ($P = 0.05$). The maize/millet system produced a higher straw yield (6303 kg/ha) than the maize/barley system (4507 kg/ha). Straw yield was not significantly different between the treatments ($P = 0.85$). The grass plot gave the highest straw yield (4970 kg/ha) and the control plot gave the lowest (4660 kg/ha).

In 2002 the straw yield was significantly different between the cropping systems ($P = 0.10$). The maize/millet system produced a higher straw yield than the maize/barley system. Straw yield was not significantly different between the treatments ($P = 0.73$). However, the closed plot produced the highest straw yield (8076 kg/ha) followed by the grass plot (7712 kg/ha). The control produced the lowest straw yield (5988 kg/ha). Both interventions gave higher straw yields than the control. The difference between the mean of interventions and the control and between the two interventions was insignificant ($P = 0.25$) in all years.

The above results confirm that there is a greater contribution from millet than barley in terms of total grain yield. Amongst the treatments, the closed plot produced a higher yield in the first and last years and the grass plot produced a higher yield throughout the experimental period than the control. The grass was not well established at the beginning of the experiment but established satisfactorily in the second year. This resulted in a better yield performance the following year. Results indicate that intervention can increase the productivity of the field.

Table 5.11 Effect of cropping systems and treatments on crop grain yields (kg/ha) at Landruk.

Factors	2000	2001	2002
Cropping system			
Maize/millet	3692	4098	5317
Maize/wheat/barley	3435	3135	4150
SED	-	-	-
Treatment			
Closed plot	3992	3315	5135
Grass plot	3727	3497	5640
Control (Farmers' practice)	3356	3171	4476
Mean	**3693**	**3327**	**5084**
SED	**298.1**	**514.5**	**787.4**

Table 5.12 Effect of cropping systems and treatments on crop residue (straw) yields (kg/ha) at Landruk.

Factors	2000	2001	2002
Cropping system			
Maize/millet	13044	6303	8005
Maize/wheat/barley	18280	4507	4275
SED	-	-	-
Treatment			
Closed plot	15418	4967	8076
Grass plot	14521	4970	7712
Control (Farmers' practice)	13120	4660	5188
Mean	**14353**	**4866**	**7259**
SED	**952.2**	**562.0**	**1469.6**

5.3.11 NPK uptake by crops

Samples of grain and crop residue were analysed for NPK during 2002. There was no significant difference in total NPK uptake between treatments ($P \geq 0.2$), [Table 5.13]. However, all NPK uptakes were highest in the closed plot followed by the grass plot and lowest in the control plot. This indicates that more nutrients were available during the growth period of the crops in the closed plot and the plot of grass planted in risers compared with control plot.

Table 5.13 NPK uptake by crops at Landruk (2002).			
Treatment	N kg/ha	P kg/ha	K kg/ha
Closed plot	144	41	160
Grass plot	140	40	162
Control (Farmers' practice)	104	33	115
Mean	**129.0**	**37.8**	**146.0**
SED	**24.5**	**8.4**	**30.3**

5.3.12 Grass biomass and NPK uptake in grass

Grass production was recorded from the plot of *Setaria aneps* planted in risers and from native grass in the control plot during 2002. Grass samples from both the plots were analysed to calculate NPK uptake (Table 5.14). Mean grass production was higher in *Setaria aneps* (2.7 kg/m^2) than native grass (2.5 kg/m^2). N uptake was found to be higher in native grass than in *Setaria aneps.* The uptake of P and K was higher in *Setaria aneps* than in native grass.

Table 5.14 Grass biomass and NPK uptake in grass in risers at Landruk (2002).					
Treatment	Grass kg/m^2	Moisture %	N g/m^2	P g/m^2	K g/m^2
Grass plot	2.7	89	15.3	2.9	18.1
Control (Farmers' practice)	2.5	89	17.8	2.6	16.9

5.3.13 Nutrient contents in rain water

NO_3-N, P and K contents were analysed in rainwater samples. In 2000 a total of 9.1, 0.6 and 4.0 kg/ha/yr NPK contributed to the fertility of *bari*. 24.0, 0.5 and 11.3 kg/ha/yr NKP contributed to the fertility in 2001. In 2002 21.7 kg/ha N and 10.4 kg/ha/yr K contributed to the fertility.

5.4 DISCUSSION

Sediment loss results show that soil loss at Landruk, a high rainfall area, varied from 886.0 to 7256.0 kg/ha/yr. The variation in sediment yield between the years and between the sites is due to high rainfall variability (Garcia-Oliva *et al*., 2002). This variation is not linked to the amount of rainfall or the cropping system. High rainfall areas received more rain in 2001 but lost less soil compared with 2000 and 2002. In the second year, in most of the research plots, the cropping system was maize/barley and the soil loss was reduced even with high rainfall. However, loss of soil in 2002 was higher from the maize/barley cropping system than from the maize/millet system. Statistical analysis shows a very low level of confidence between the treatments. However, the difference between the two means was greater. Most observations between the farmers' fields are significantly different due to variation in farm management. The means of the cropping systems have larger errors because one cropping system is replicated four times and the other is non-replicated. The soil loss in 2000 was higher after May 31st (in the mid-monson) and in other years it was higher before May 31st (in the early-monsoon). The effect of intervention, especially diversion of run-on (closed plot), shows a positive trend in reducing soil loss compared with the control in which run-on occurs. Peiqing *et al.* (2002) reported additional sediment delivery downslope caused by upslope runoff. However, the closed plot lost more soil compared with the control during the late-monsoon (after 31 July) in 2001 and 2002.

Grass planted in terrace risers increased soil loss in the first year and second years compared with the control but in the third year it decreased compared with the control. The main reasons for higher soil loss from the plot of grass planted in terrace risers are soil disturbance during grass planting and poor establishment in the first year. In the second year grass was planted densely and established partially. However, it still failed to have an effect on soil loss. In the third year grass was satisfactorily established in terrace risers and minimised soil loss. Results therefore indicate that riser planting could minimise soil loss once the grass is well established. The presence of perennial forage crops in the rotation has been found to be important in minimising runoff and erosion (Chisci *et al.*, 1989). However, farmers are limited in the amount of land they can afford to use for forage crop planting in crop rotation. The terrace risers are not used for crops and these are covered by native grass (used for cattle feeding). If the terrace riser is planted with high quality fodder grass that does not affect the crops in the terrace, farmers can benefit in a variety of ways. Terracing makes a new landscape and terrace risers constitute a very important component of the terraced hillside (Critchley and Bruijnzeel, 2002). The protection of terrace risers is important and it is achieved by planting grasses. These provide good quality fodder whilst managing fertile soils. Terrace risers act as grass strips, helpful in reducing soil erosion from cultivated land where the erosion rate is not much higher than 68.2 t/ha (Lewis and Nyamulinda, 1996).

Selection of grass species for the terrace risers should take into consideration the aim of good fodder provision. Selection of a species depends on the shading effect for the crops in terraces, the load to the risers and palatability for animals. *Setaria aneps* has been found to be satisfactory but nutrient content (especially N) was higher (31.3 g/kg) in native grass species compared with the grass sample from the plot of *Setaria aneps* planted in terrace risers (26.0 g/kg). However, P and K contents were higher in the grass sample collected from the risers planted with *Setaria.* The total fresh biomass of the grass was 2.7 kg/m^2 with 89.0 % moisture content from the *Setaria* planted riser and 2.6 kg/m^2 with 89.3 % moisture content from the control plot.

Previous research in Nepal suggests that more soil loss occurs during the early-monsoon. However, this study shows higher loss in the mid-monsoon (from June to July in 2000). It was more than 58.1 % from different treatments. In other years results are similar to previous findings (Gardner *et al.*, 2000). Carver and Schreier (1995) reported that soil loss was 0.02 t/ha during the main monsoon compared with 20 t/ha in the pre-monsoon period with similar rainfall in upland conditions. Soil loss was higher than 64.0 % in the early-monsoon, 12.6 to 27 % in the mid-monsoon (June - July) and 6.0 to 16.9 % in the late-monsoon (after 31 July) in different treatments. The rainfall and KE in the early-monsoon of 2000 was lower, causing less runoff and soil loss compared with the same period in other years. The pulverised soil was lost in the following period when rainfall and KE exceeded the resistance of the soil to runoff. Low rainfall during the early-monsoon period might not have been sufficient for vegetation growth in the mid-monsoon and the soil became susceptible to loss in runoff due to lack of cover.

The pattern of rainfall played an important rôle in the seasonal distribution of soil loss. The total KE produced during rainfall is well correlated with rainfall each year ($r \geq 0.64$). However, KE and soil loss are not necessarily correlated. A strong positive correlation between KE and soil loss ($r = 0.48 - 0.79$) was observed during 2000. This relationship was weak but positive in 2001 and there was no relationship in 2002. Runoff is observed to decrease under increasing levels of crop canopy cover at the same rainfall intensity showing an inverse relationship between crop canopy and soil loss (Narayan and Bhushan, 2002). Soil loss then decreases even with an increase in KE because vegetation growth covers the surface and root growth increases resistance to soil runoff. Climatic conditions and plant cover are the most significant factors affecting soil erosion (Monsikhaniemi and

Salmi, 1992). Fiener and Auerswald (2002) reported that grassed waterways reduced runoff and sediment delivery by 39% and 82%, respectively. Run-on flows over the risers and reches the bottom terrace with a high velocity, increasing erosion. The grassed risers trap sediment and enhance infiltration, hence reducing erosion.

Erosion occurs in the topsoil. The loss of soil is important because it carries away plant nutrients. The topsoil consists of significantly higher quantities of organic matter, N and available P than subsoil (Claassen and Zasoski, 1998) but after erosion it becomes infertile. Amongst the nutrient elements, N is the most important nutrient to be lost along with sediment. Mingxang *et al.* (2002) found a decrease in organic matter from the top to lower layers of the soil profile. Results show that diversion of run-on minimised soil N loss from 8.4 kg/ha/year (control) to 4.65 kg/ha/year.

The other important element to be lost in sediment is organic carbon. The highest amount was found in the sediment from the control (114.27 kg/ha/year) and diversion of run-on reduces the loss of organic carbon. The loss of organic matter further increases erodibility of the soil (Charman and Roper, 2000) because, when present, it contributes to soil conservation by developing soil structure stability as it aggregates. Soil aggregates resist the destructive force of raindrop impact. The grass barrier in terrace risers minimised soil loss at Landruk and also tended to minimise nutrient losses in leachate.

Loss of nutrients is very high in leachate, especially N (in the form of nitrate) and K. Soil particle size distribution analysis gives the result to be sandy loam, a very light soil prone to nutrient leaching. The amount of nutrients lost in leachate varied from year to year. Intervention had either no effect or it increased loss of N in leachate compared with the control. Leachate from the grass barrier in terrace risers contains slightly lower K and in the plot of run-on diversion contains higher K compared with the plot receiving run-on in the control. In addition, soil organic carbon can be lost in percolation as well as in surface runoff water (Bajracharya,1998). This is not measured in the present study. Generally soil N is found in organic matter and negligible amounts of nitrogen are available from geological material. It has been reported that N broken down from organic matter (as NO_3-N) is rarely leached from the soil during the growing season except in the case of coarse sandy soil (Davies *et al.*, 1993).

The loss and recycling of nutrients in the field shows that the control has the lowest effect on N in the soil reservoir in which N is depleted at the rate of 1.1 kg/ha/year. It is depleted at the higher rate of 43.11 - 48.71 kg/ha/year from intervention plots. The loss of N through denitrification and volatilization is not considered here. The same trend has been observed in the depletion of P and K from the soil reservoir (Table 5.15). However, some nutrients are added from rainfall. The effect of intervention was reflected in the productivity.

Grain yields were higher in the maize/millet system but the maize/barley system showed no response. Different cropping systems may have different levels of fertility requirement (Stocking and Murnaghan, 2001). Results indicate that the maize/millet system has a low soil fertility requirement and the maize/barley system requires a high level of soil fertility to be adopted by farmers in the yearly rotation.

Table 5.15 Soil nutrient status (Landruk).

Variables	Diversion run-on			Grass plot			Control		
	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)	N (kg/ha)	P (kg/ha)	K (kg/ha)
Leaching	28.0	0.2	35.3	18.3	0.2	26.7	17.3	0.2	30.7
Runoff	2.6	0.1	3.3	5.2	0.1	4.9	4.6	0.2	8.8
Sediment	10.7	0.2	0.7	14.5	0.3	0.8	18.1	0.3	1.0
Crop	126.3	36.9	139.1	122.3	35.8	140.9	86.9	28.5	93.4
Total uptake	167.6	37.4	178.4	160.3	36.4	173.3	126.9	29.2	133.9
FYM	101.0	18.5	65.2	88.1	15.3	67.8	102.3	20.4	78.0
Rainfall	23.5	0.9	11.9	23.5	0.9	11.9	23.5	0.9	11.9
Total input	124.5	19.4	77.1	111.6	16.2	79.7	125.8	21.3	89.9
Soil	1980.0	54.23	187.9	1980.0	61.4	143.5	2380.0	57.0	229.5
Balance	**- 43.1**	**-17.9**	**-101.3**	**-48.7**	**-20.2**	**-93.6**	**-1.1**	**-7.8**	**-44.0**
Grass traps				152.7	28.9	181.2	178.5	26.4	168.6

CHAPTER 6

EVALUATION OF SOIL AND NUTRIENT LOSSES IN THE CITRUS GROWING POCKETS OF THE MIDDLE HILLS: A BENCH TERRACING LAND USE SYSTEM IN MEDIUM RAINFALL AREAS

6.1 INTRODUCTION

The middle hills of Nepal contain different agro-ecological pockets. These pockets show variation in vegetation, climate, soil and farmers' cultivation practice. Most of the middle hills are suitable for citrus cultivation, this practice extending from east to west in pocket areas. The middle hills are generally in sub-tropical to warm temperate climatic regions (Carson *et al.*, 1986). Vaidya and Floyd (1997) reported that, in a survey site, 63.1 % of households grow mandarin oranges. The present policy in Nepal has developed an agricultural plan giving priority to cash crops and fruit cultivation in the hills. This along with the rapid development in transportation in the hills, supporting the marketing facility, has further increased citrus fruit production. Bandipur is a representative site of citrus cultivation having a highly diversified cropping system (Tripathi *et al.*, 1999). It receives medium rainfall ranging from 1000 to 2000 mm in summer (May to Sept.) and has bench terraces of different sizes and slope angles less than 5°. The land extends from 800 m to 1200 m asl. The slope angle and the width of the terrace gives the slope steepness value and slope length (Morgan, 1995). These are key factors affecting soil erosion and ultimately soil fertility.

Each farmer in the Bandipur area has at least one citrus orchard. Some farmers grow citrus crops commercially and have extensive orchards; others have only small orchards but there is a general increase in citrus cultivation to provide a source of income. A scarcity of labour has encouraged farmers to turn their land over to citrus cultivation. The average farmer in Bandipur has 66% *bari* land and uses traditional cropping systems in addition to citrus cultivation (Acharya, 2000).

Trees play a crucial rôle in nutrient conservation by increasing water infiltration rate, soil moisture levels and recycling nutrients from depth (Campbell *et al.*, 1992). Citrus cultivation could therefore be important factor in soil fertility management in the middle hills as well as a source of income.

Amongst the traditional cropping systems, the maize-based cropping system is the most important in this area. However, different crops such as wheat, barley, mustard and blackgram are grown after the maize. Farmers grow intercrops in the citrus orchards only whilst the citrus plants are small.

Soil fertility varies with the cropping system. Changes to the cropping system are governed by climatic conditions, soil type and farmers' needs. Decreasing soil fertility is a common problem (irrespective of the cropping system) due to decreasing resources, soil erosion and nutrient loss.

The objective of this study is to evaluate existing farming systems for minimising soil and nutrient loss in citrus growing pocket areas.

6.2 MATERIALS AND METHODS

Bandipur was selected as a site representative of citrus cultivation pocket areas in the middle hills having medium rainfall and the bench terracing land cultivation system. Existing cropping systems in this area were evaluated. Six plots were studied, all of which had been used in a previous soil erosion study conducted by QMWC, University of London and ARS, Lumle (Gardner *et al.*, 2000). These plots were located in four farmers' fields as follows:

In one plot maize/millet was grown in the first year, upland rice-fallow-fallow in the second year and maize-fallow-fallow in the third year. The plot comprised two wide terraces, each being more than 9 m in width, called the wide-terraced maize-based (WT/MB) plot.

In the second plot, consisting of five terraces, there was a young citrus orchard (plants were about 10 years old) with an intercrop of maize and a summer legume. In the first year the latter was soybean, in the second year it was cowpea and in the third year the only intercrop was cowpea . This plot is called young citrus orchard (YCO).

The third, fourth and fifth plots were in a single block in a narrowly-terraced field. Each plot contained six terraces of varying width. Maize (following maize-fallow-fallow system) was grown in all plots in this block with the exception of the plot in the middle terrace in which upland rice replaced maize in the first and third year and the lower three terraces were planted with soybean after maize in the third year. This is called narrow-terraced maize-based (NT/MB).

The sixth plot consisted of four terraces of varying width and contained fully grown citrus trees (over 25 years old), termed old citrus orchard (OCO). There was no intercropping.

In the rainy season of the second year *Setaria aneps* (a fodder grass) was planted on the terrace risers of the fifth plot. The third and fourth plots were control plots. Thus four practices and one new intervention (grass planted in terrace risers) were evaluated in four farmers' fields.

The length of each terrace was five metres and the total width of all terraces in each plot was 20 metres (plot area = 5m x 20m = 100 m^2). The sixth plot was an exception to this as its total width was 12 metres. Run-on was not permitted into any plot. This was achieved by closing off each plot with metal sheets from all four sides. Rainfall, runoff, leachate, nutrient loss and sediment loss were measured as previously described. Soil samples were collected and analysed but crop yields and manure/fertilizer application were not recorded. Means of data were compared in order to evaluate the above cropping systems.

6.3 RESULTS

6.3.1 Rainfall and its erosivity

Rainfall in Bandipur (2000-2002) is presented in Fig. 6.1. Rainfall over the whole season of the first, second and third year was 1249.6, 2042.0 and 1680.7 mm respectively.

In 2000 rainfall produced a total KE of 19152.7 MJ mm/ha/h and a maximum KE of 4284.2 MJ mm/ha/h in one rainfall event. Of the total rainfall, 523.5 mm occurred in the early-monsoon period producing a total KE of 10519.8 MJ mm/ha/h with a maximum KE of 2420.9 MJ mm/ha/h in one rainfall event. Mid-monsoon rainfall was 377.6 mm with a total KE of 8633.0 MJ mm/ha/h and maximum KE of 4284.2 MJ mm/ha/h in one rainfall event. The late-monsoon rainfall was 348.6 mm but its KE was not recorded.

In 2001 total rainfall was 2042 mm with a total KE of 27049.0 MJ mm/ha/h and a maximum KE of 4386.5 MJ mm/ha/h in one rainfall event. Rainfall in the early-monsoon was 618.0 mm, producing KE of 16726.1 MJ mm/ha/h with a maximum KE of 1467.7 MJ mm/ha/h in one event. The mid-monsoon rainfall was 1009.0 mm, producing the KE of 10322.9 MJ mm/ha/h with a maximum KE of 1467.7 MJ mm/ha/h in one event. Rainfall in the late-monsoon was 416.0 mm but its KE was not recorded.

In 2002 the automatic rain gauge did not record rainfall so the EI of the rain was not calculated. Total rainfall was recorded from the manual rain gauge and its distribution was found to be 262.0 mm in the early-monsoon, 839.3 mm in the mid-monsoon and 579.4 mm in the late-monsoon.

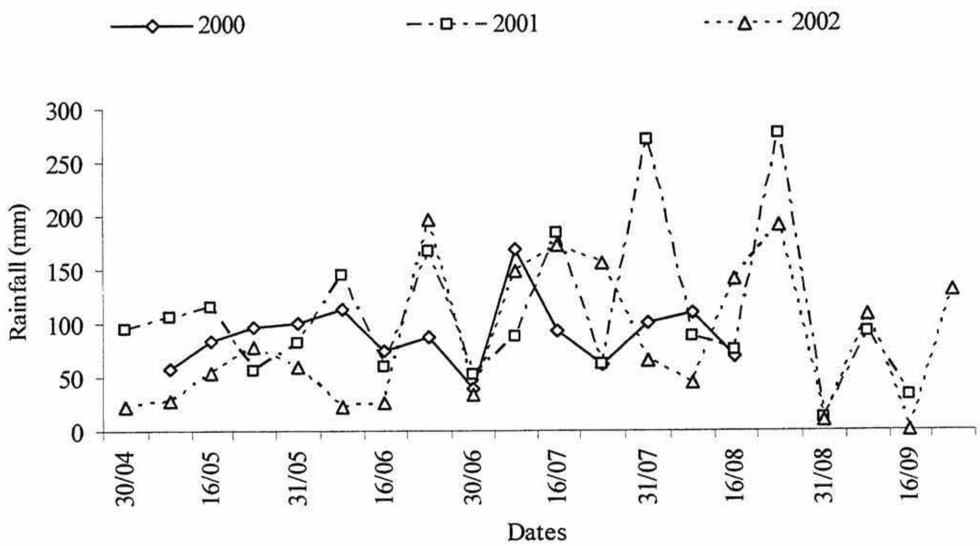


Fig. 6.1 Rainfall at Bandipur (2000-2002).

6.3.2 Runoff

In 2000 runoff was highest (16.8 % of the annual rainfall) in the old citrus orchard. Minimum runoff was from the young citrus orchard (2.6 %). Runoff from the narrow-terraced maize-based system was 8.3 % and from the wide-terraced maize-based system was 3.4 % (Fig. 6.2 a). The amount of runoff was 209.7, 32.6, 103.5 and 83.0 mm from old citrus orchard, young citrus orchard, narrow-terraced and wide-terraced maize-based systems respectively (Fig 6.3 a).

In 2001 runoff from the old citrus orchard was 5.2 % (154.1 mm), from young citrus orchard was 2.8 % (34.4 mm), from the narrow-terraced maize-based system was 8.5 % (148.6 mm) and from the wide-terraced maize-based system was 3.9 % (50.3mm). Highest runoff was recorded from the narrow-terraced maize-based system and the lowest was recorded from the young citrus orchard (Figs.6.2 b and 6.3 b).

In 2002 the highest runoff was 5.8 % (97.6 mm) from the narrow-terraced maize-based system followed by 4.7 % (79.5 mm) from the old citrus orchard. Minimum runoff was 0.4 % (6.0 mm) from the young citrus orchard. Grass planted in terrace risers reduced runoff to 1.9 % (32.6 mm) from 5.8 % (97.6 mm). Higher runoff occurred in the early-monsoon from all plots except the old citrus orchard. This produced more runoff in the mid-monsoon. The early-monsoon runoff trend was similar to the whole season runoff trend. In the mid-monsoon the old citrus orchard produced more runoff than the narrow-terraced maize-based system. The old citrus orchard produced the highest runoff and the wide-terraced maize-based system produced the least runoff in the late-monsoon (Figs. 6.2 c and 6.3 c).

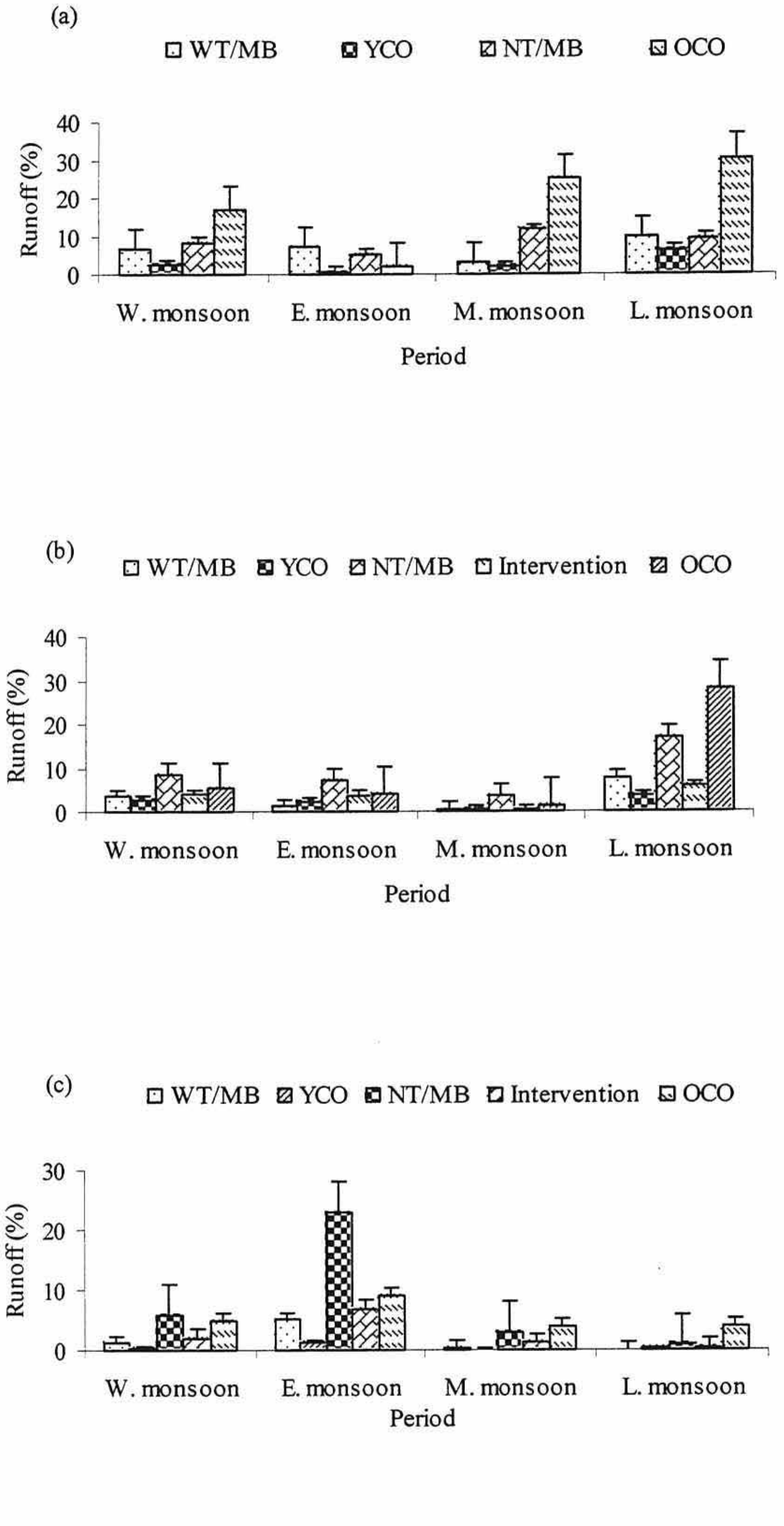


Fig. 6.2 Runoff (percentage of rainfall) during (a) 2000, (b) 2001 and (c) 2002 at Bandipur.

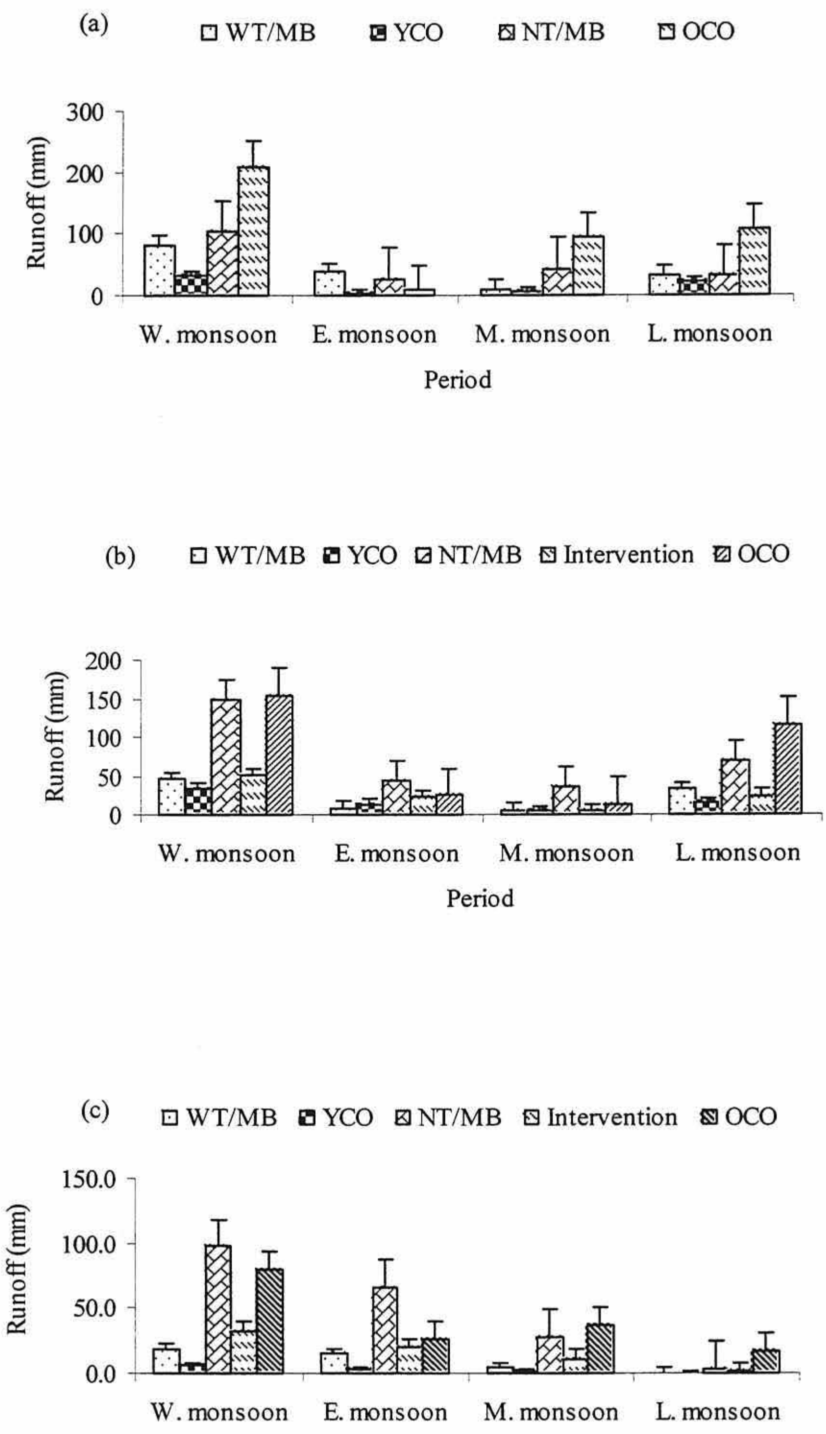


Fig. 6. 3 Runoff amount (mm) during (a) 2000, (b) 2001 and (c) 2002 at Bandipur.

6.3.3 Eroded sediment

In 2000 the old citrus orchard lost the highest amount of sediment (1316.3 kg/ha) followed by the narrow-terraced maize based system. The lowest sediment loss was 201.8 kg/ha from the plot of young citrus orchard. Loss from the wide-terraced maize based-system was 617.0 kg/ha. In the early-monsoon the narrow-terraced maize-based system lost the highest amount of sediment followed by the wide-terraced maize-based system. In the mid- and late-monsoon the old citrus orchard lost the highest amount of sediment followed by the narrow-terraced maize-based system. Young citrus orchard lost the least sediment in all periods of the monsoon (Fig. 6.4 a). Sediment loss was 31.1 to 75.0 % in the early-monsoon, 12.5 to 39.0 % in the mid-monsoon and 12.5 to 41.5 % in the late-monsoon from different plots.

In 2001 sediment loss was highest (1578.0 kg/ha) from the narrow-terraced maize-based system followed by 844.1 kg/ha from the plot of grass planted in terrace risers. The lowest loss of sediment was from the young citrus orchard (162.9 kg/ha). Sediment loss from the old citrus orchard and wide-terraced maize-based system was 652.0 and 221.9 kg/ha respectively. The narrow-terraced maize-based system had the highest loss of sediment in all monsoon periods. The lowest loss of sediment was recoded from the young citrus orchard in the early- and late-monsoons. The wide-terraced maize-based system lost the least sediment in the mid-monsoon. Sediment loss was reduced by planting grass in terrace risers in all monsoon periods (Fig. 6.4 b). Sediment loss was found to be 9.7 to 66.0 % of rainfall in the early-monsoon, 4.4 to 41.6 % of rainfall in the mid-monsoon and 23.7 to 48.7 % of rainfall in the late-monsoon.

In 2002, as in 2001, the narrow-terraced maize-based system lost the highest amount of sediment (2804.0 kg/ha) followed by the plot of grass planted in terrace risers (2094.6 kg/ha). The lowest sediment loss of 269.5 kg/ha came from the young citrus orchard. The wide-terraced maize-based system and the old citrus orchard lost 744.6 and 679.5 kg/ha respectively (Fig. 6.4 c). In the early-monsoon sediment loss was 38.6 % to 93.4 % of the annual loss. The narrow terraced maize-based system lost the highest quantity of sediment followed by the plot of grass planted in terrace risers. The lowest sediment loss was observed in the young citrus orchard. In the mid-monsoon the sediment loss was 6.5 to 60.8 % of the annual loss. The highest loss of sediment was observed in the narrow-terraced maize-based system and the lowest loss was observed in the wide-terraced maize-based system. In the late-monsoon the loss of sediment was 0.1 to 21.1 % of the annual loss. The highest loss was observed in old citrus orchard and the lowest loss was observed in the wide-terraced maize-based system. The maize-based cropping system lost more soil compared with citrus orchard in Bandipur. Wide terracing or grass planted in risers reduced soil erosion. High soil loss events were recorded in different years (Figs.6.5).

Regression analysis shows that the relationship between KE of rainfall and soil loss was linear and positive in most of the farming systems in Bandipur (Figs.6.6 and 6.7). However, the relationship between KE and soil loss was significant mainly in the wide-terraced maize-based system. There was no relationship between KE and soil loss in narrow terraced maize based system. This relation tended towards linear and positive when terrace risers were planted with grass (*Setaria aneps*). Similarly, the relationship between KE and soil loss was linear and positive in the young citrus orchard but tended to be negative in the old citrus orchard. Rainfall occurring with high KE resulted in irregular soil loss because of the status of ground cover, the citrus canopy and the width of terrace-showing no relation, a quadratic relation or a negative relation between KE and soil loss. Most soil loss occurred below 2000 MJ mm/ha/h. The relationship between KE and soil loss was highly significant, linear and positive below 600 MJ mm/ha/h in the young citrus orchard in 2000.

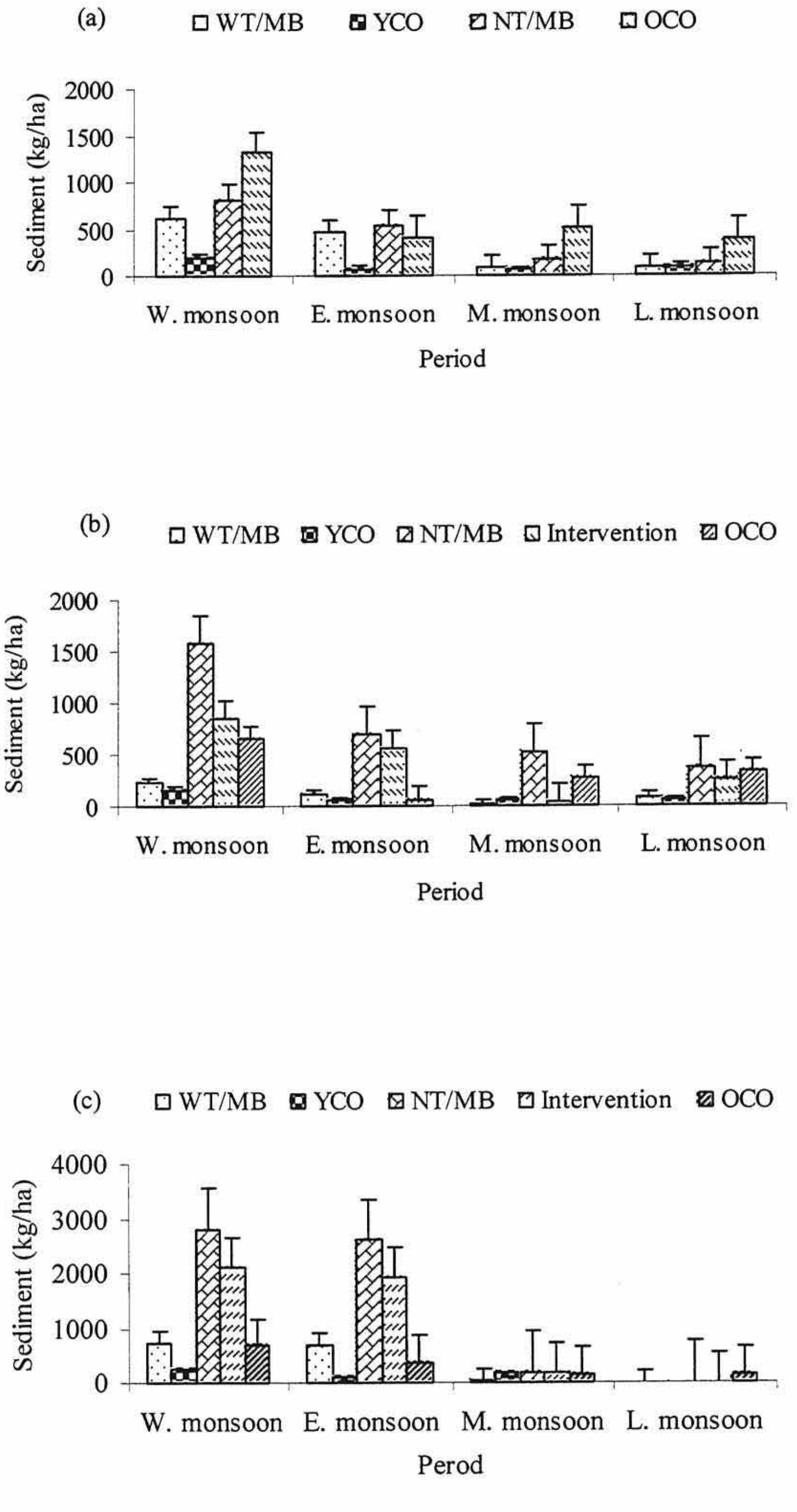


Fig. 6.4 Eroded sediment during (a) 2000, (b) 2001 and (c) 2002 at Bandipur.

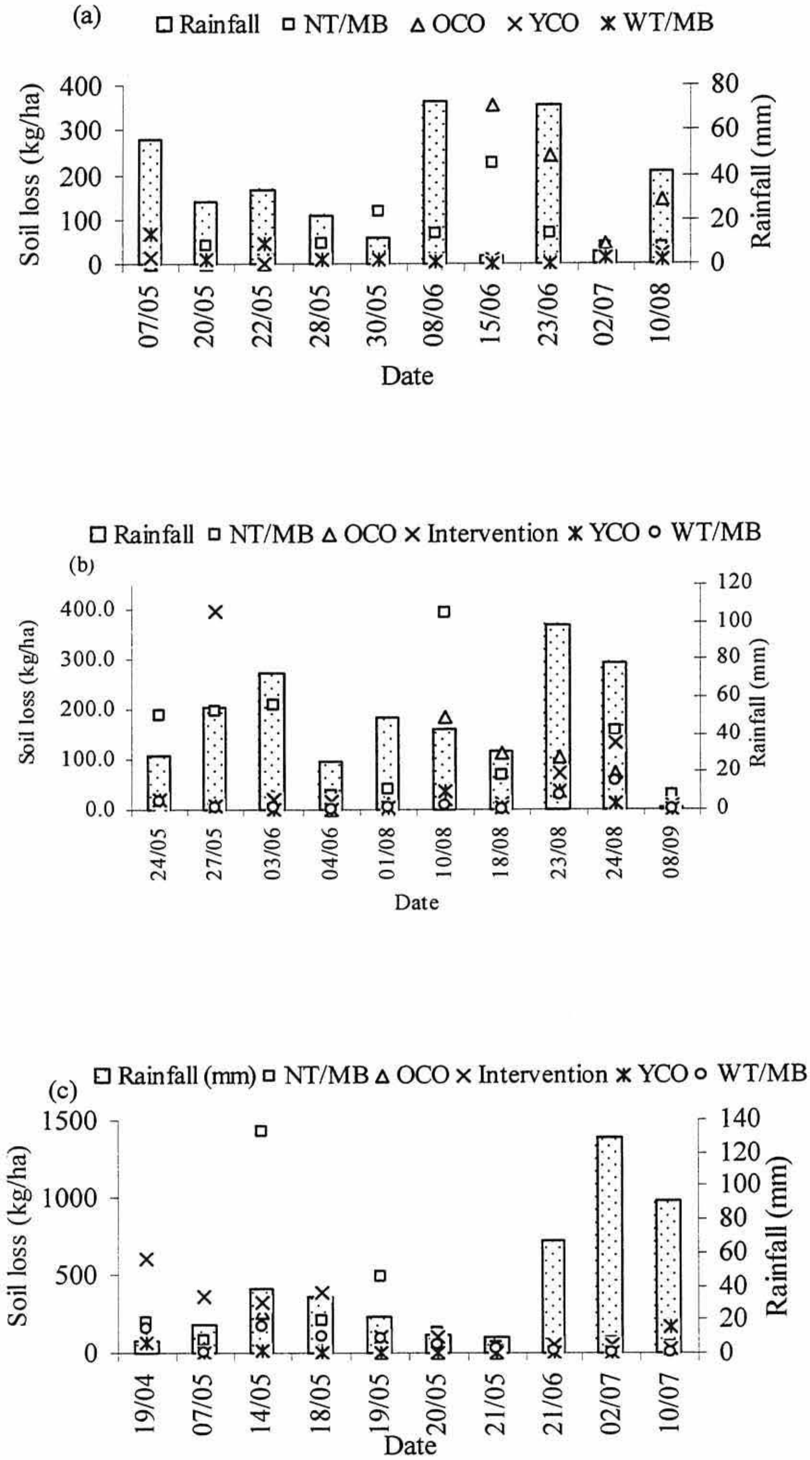


Fig. 6.5 Soil loss events at Bandipur (a) 2000, (b) 2001 and (c) 2002.

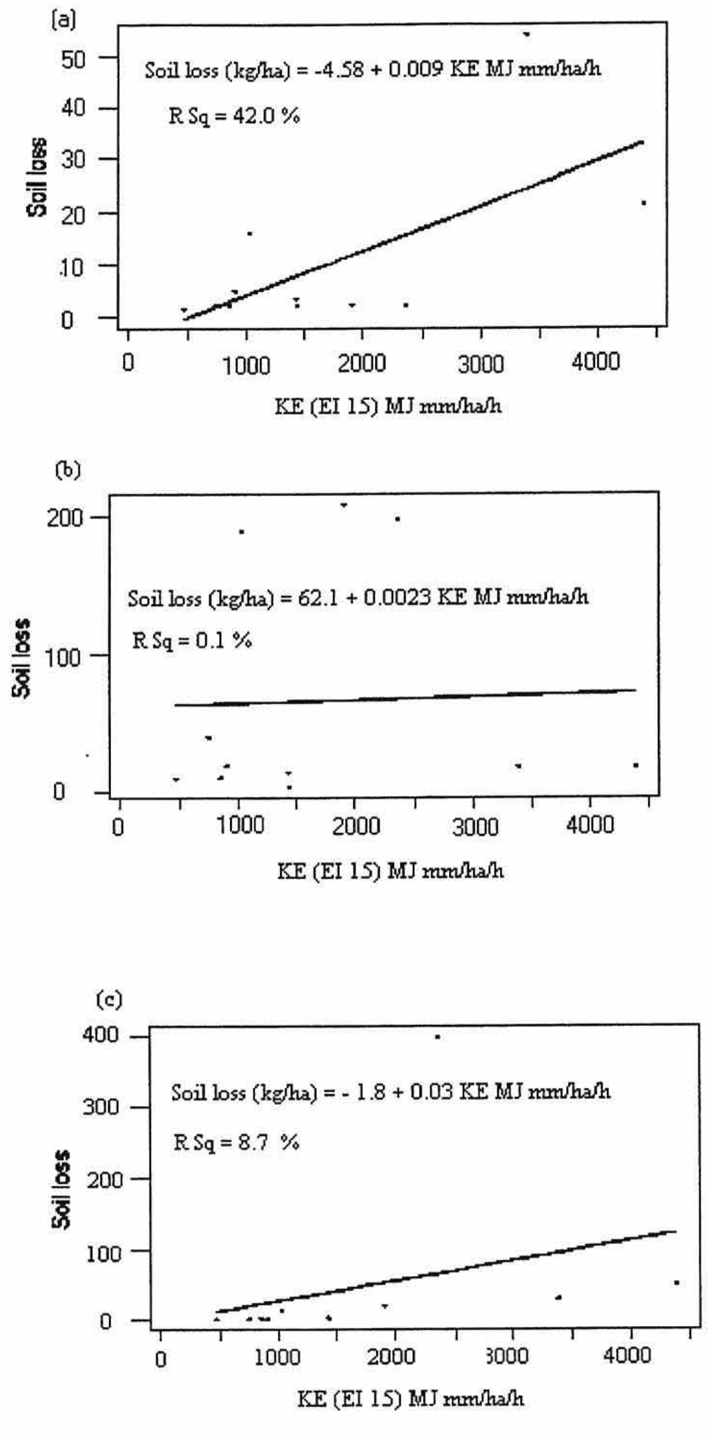


Fig. 6.6 Regression plot showing the relationship between KE and soil loss in (a) the wide-terraced maize-based system, (b) narrow-terraced maize-based system and (c) grass planted in terrace risers during 2001 at Bandipur.

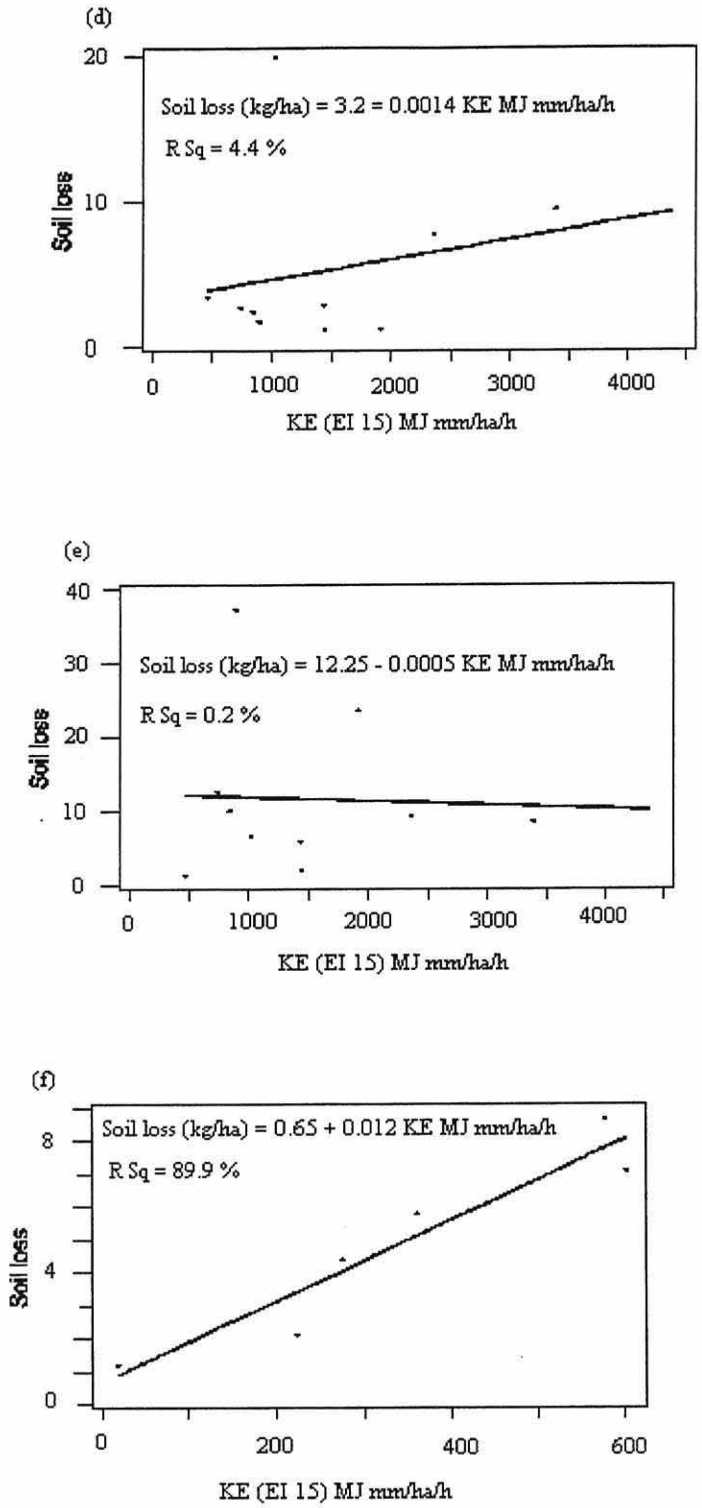


Fig. 6.7 Regression plot showing the relationship between KE and soil loss in (d) young citrus orchard, (e) old citrus orchard during 2001 and (f) young citrus orchard during 2000 at Bandipur.

6.3.4 Soluble nutrients in runoff

The loss of dissolved nutrients in runoff was always found to be low. Figs. 6.8 (a), (b) and (c) show nutrient loss in runoff during 2000 - 2002. In 2000 the highest loss of NO_3-N was 1.2 kg/ha from the old citrus orchard and the lowest was from the young citrus orchard. Loss of P was also highest from the old citrus orchard (0.79 kg/ha) and lowest from the young citrus orchard. Loss of K was highest from the old citrus orchard (4.2 kg/ha) followed by 2.2 kg/ha from the narrow-terraced maize-based system. The lowest loss of K was found in the young citrus orchard.

In 2001 the old citrus orchard lost the highest quantity of NO_3-N (3.3 kg/ha) in runoff followed by the narrow-terraced maize-based system (3.0 kg/ha). The lowest loss of N was 0.8 kg/ha from the wide-terraced maize-based system, similar to the loss from young citrus orchard. Loss of P was highest (0.7 kg/ha) from the old citrus orchard. Loss of K in runoff was highest (7.1 kg/ha) from the old citrus orchard followed by the narrow-terraced maize-based system. The lowest loss of K was 1.1 kg/ha from the wide-terraced maize-based system.

In 2002 the loss of NO_3-N was highest from the narrow-terraced maize-based system (1.6 kg/ha) followed by the old citrus orchard (1.4 kg/ha). The lowest loss of N was from the young citrus orchard (0.2 kg/ha). Loss of K was highest from the old citrus orchard (4.4 kg/ha) followed by the narrow-terraced maize-based system (3.0 kg/ha). Results indicate that the loss of nutrients in runoff is low especially in the case of P. Loss of N is comparatively high in the old citrus orchard and the narrow-terraced maize-based system. The variation in nutrient loss between different terraces and cropping systems is due to differences in amounts of runoff.

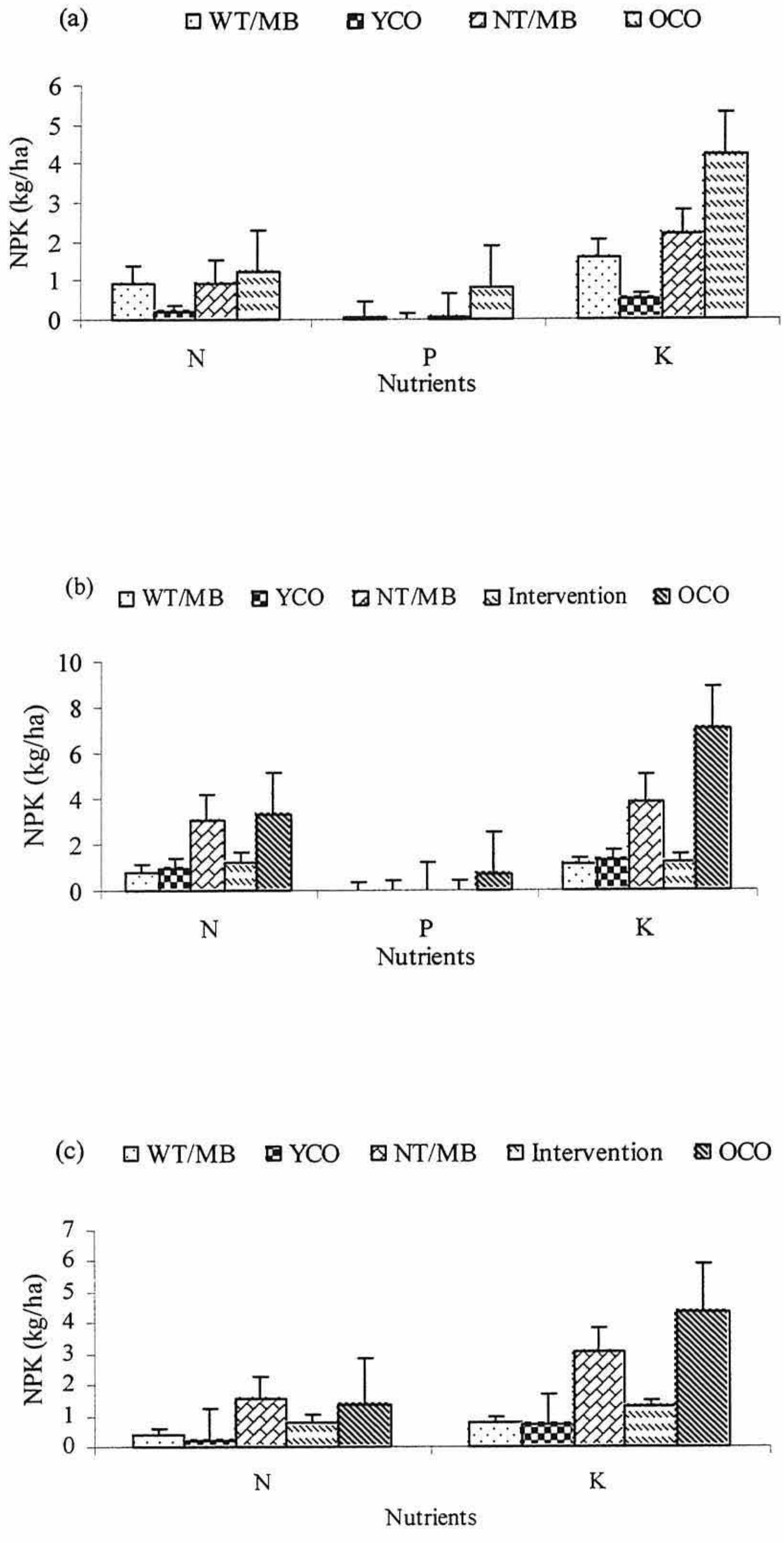


Fig. 6.8 Nutrients in runoff during (a) 2000, (b) 2001 and (c) 2002 at Bandipur.

6.3.5 Nutrient content in eroded sediment

Eroded sediment was analysed for organic carbon, total nitrogen, available P and exchangeable K. In 2000 the highest organic carbon content was in eroded sediment from the young citrus orchard (24.0 g/kg) followed by the sediment collected from the wide-terraced maize-based system (23.5 g/kg). The lowest organic carbon content was in eroded sediment from the narrow-terraced maize-based system (14.7 g/kg). Despite a high loss of eroded sediment there is not much loss of organic carbon due to low organic carbon concentration. Total nitrogen content was the same in the eroded sediment collected from all plots (0.6 g/kg) except in the young citrus orchard which had comparatively higher N (1.2g/kg). Available P was highest in the eroded sediment collected from the old citrus orchard (81.8 mg/kg) followed by the eroded sediment from the young citrus orchard (55.7 mg/kg). The lowest available P was 30.9 mg/kg in the sediment collected from the wide-terraced maize-based system. Exchangeable K was only analysed in sediments from the young citrus orchard and the narrow terraced maize-based system (155.6 and 194.5mg/kg respectively) [Table 6.1].

In 2001 the concentration of organic carbon was highest (54.4 g/kg) in sediment from the wide-terraced maize-based system and the lowest from the plot of grass planted in terrace risers (28.8 g/kg). The organic carbon content was 49.5, 46.7 and 40.9 g/kg in the eroded sediment from the old citrus orchard, young citrus orchard and narrow terraced maize-based system respectively. Total N content was highest in the sediment collected from the wide-terraced maize-based system (0.35 g/kg) followed by the old citrus orchard (0.34 g/kg). Lowest N content was found in sediment collected from the narrow-terraced maize-based system (0.19 g/kg). The young citrus orchard and the plot of grass planted in terrace risers had sediment containing N content of 0.30 and 0.33 g/kg respectively. Available P was highest (362.5 mg/kg) in sediment from the old citrus orchard followed by the young citrus orchard (186.4 mg/kg). The lowest P content was found in the sediment from the narrow-terraced maize-based system (66.0 mg/kg). Sediment from the plot of grass planted in terrace risers had a high content of P (116.9 mg/kg) compared with non-grass planted terrace risers or the wide-terraced maize-based system (66.0-83.2 mg/kg). Exchangeable K was compared in sediment from the plot of grass planted in terrace risers and from the non-grass planted terrace risers and it was found to be higher in the former (372.0 mg/kg) [Table 6.2].

In 2002 organic carbon in eroded sediment was found to be lower than in previous years. Organic carbon content was highest in the sediment collected from the narrow-terraced maize-based system (14.5 g/kg) followed by the old citrus orchard (12.8 g/kg). The lowest organic carbon content was found in sediment from the wide-terraced maize-based system (9.5 g/kg). Organic carbon contents were 11.1 and 12.3g/kg in eroded sediment from the young citrus orchard and the plot of grass planted in terrace risers. Total N content varied from 2.0 to 2.6 g/kg in sediment collected from the different plots. All plots lost higher amounts of N in sediment than in previous years. The highest N content in sediment was from the young citrus orchard and narrow-terraced maize-based system (2.6 g/kg). The lowest N content in sediment was from the plot of grass planted in terrace risers (2.0 g/kg). Available P was lower in 2002 than in previous years except in the case of the wide-terraced maize-based system which had sediment containing a higher P content than its sediment in 2000. Highest P was found in sediment collected from the old citrus orchard (39.1 mg/kg) followed by the plot of grass planted in terrace risers (37.1 mg/kg). P content in sediment ranged from 34.2 to 39.1 mg/kg in the different plots. Exchangeable K was highest in sediment from the wide-terraced maize-based system (428.4 mg/kg). The lowest exchangeable K content was found in sediment from the old citrus orchard (145.8 mg/kg). The grass-planted plot and non-grass-planted plot (in terrace risers) had K content of 321.3 and 314.5 mg/kg respectively (Table 6.3).

Table 6.1 Effect of cropping systems on the nutrient element content of eroded sediment at Bandipur (2000).

Cropping system	Organic Carbon (g/kg)	Total N (g/kg)	Available P (mg/kg)	Exchangeable K (mg/kg)
Wide-terraced maize-based system	23.5	0.6	30.9	
Young citrus orchard	24.0	1.2	55.7	155.6
Narrow-terraced maize-based system	14.7	0.6	40.1	194.5
Old citrus orchard	22.1	0.6	81.8	
Mean	**21.1**	**0.8**	**52.1**	**175.0**

Table 6.2 Effect of cropping systems on the nutrient element content of eroded sediment at Bandipur (2001).				
Cropping system	Organic Carbon (g/kg)	Total N (g/kg)	Available P (mg/kg)	Exchangeable K (mg/kg)
Wide-terraced maize-based system	54.4	0.35	83.2	
Young citrus orchard	46.7	0.30	186.4	
Narrow-terraced maize-based system	40.9	0.19	66.0	335.6
Grass planted in risers (Narrow- terraced maize-based)	28.8	0.33	116.9	372.0
Old citrus orchard	49.5	0.34	362.5	
Mean	**44.0**	**0.30**	**163.0**	**353.8**

Table 6.3 Effect of cropping systems on the nutrient element content of eroded sediment at Bandipur (2002).				
Cropping system	Organic Carbon (g/kg)	Total N (g/kg)	Available P (mg/kg)	Exchangeable K (mg/kg)
Wide-terraced maize-based system	9.5	2.2	35.4	428.4
Young citrus orchard	11.1	2.6	-	
Narrow-terraced maize-based system	14.5	2.6	34.2	321.3
Grass planted in risers (Narrow-terraced maize-based system)	12.3	2.0	37.1	314.5
Old citrus orchard	12.8	2.5	39.1	145.8
Mean	**12.1**	**2.4**	**36.5**	**302.5**

6.3.6 Leachate

Leachate measurements were higher than the amount of rainfall in Bandipur in all three years. In 2000 the lowest amount of leachate was from old citrus orchard (1144.3 mm). Leachate from all other plots exceeded annual rainfall (1249.6 mm). Maximum leachate was observed in the wide-terraced maize-based system (1896.0 mm) [Fig.6.9 a]. Leachate was low in the early-monsoon, high in the mid-monsoon and then decreased in the late-monsoon.

In 2001 rainfall was 2042.0 mm. The least leachate was from the young citrus orchard (1218.2 mm) and the highest from the old citrus orchard (2982.5 mm). The amount of leachate was low in the early-monsoon in all plots. Leachate from the narrow-terraced maize-based system and the old citrus orchard was highest in the mid-monsoon and from the wide-terraced maize-based system, young citrus orchard and plot of grass planted in terrace risers was highest in the late-monsoon (Fig. 6.9 b).

In 2002 rainfall was 1680.7 mm. The lowest amount of leachate was from the plot of grass planted in terrace risers (1521.1 mm). Leachate from all the plots exceeded the annual rainfall. Highest leachate was from the old citrus orchard (2376.0 mm). Leachate was higher in the mid-monsoon than in the early-and late-monsoon periods in all plots but old and young citrus orchard produced a higher quantity of leachate in the early-monsoon compared with the late-monsoon (Fig. 6.9 c).

Excessive leachate from Bandipur soil was recorded. Bandipur soil contains a large amount of clay and therefore a hard pan may exit below the plough layer (15 cm deep) preventing the percolation of water. However, the lysimeter did not contain a hard pan and therefore allowed water percolation giving a high recording of leachate measurement.

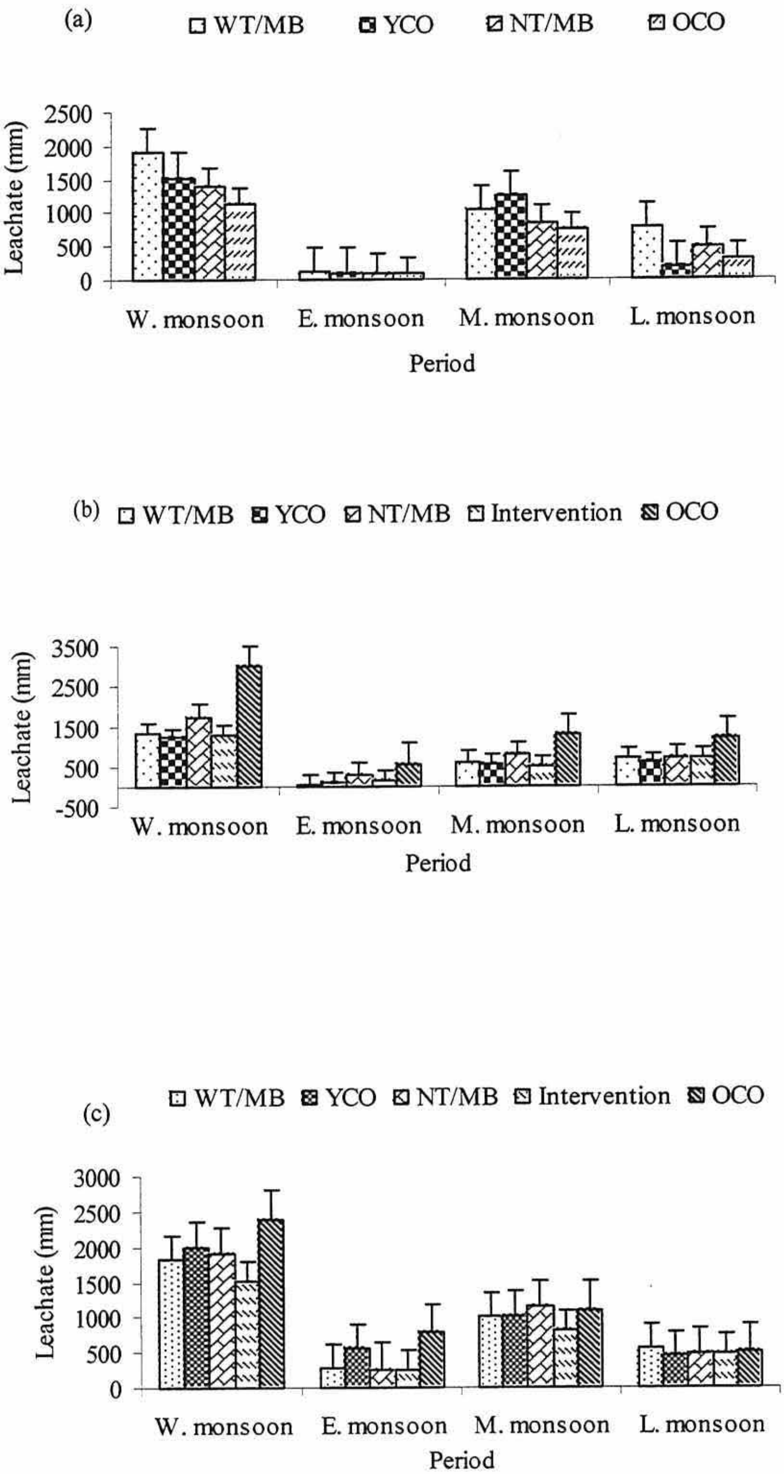


Fig. 6.9 Leachate (mm) during (a) 2000, (b) 2001 and (c) 2002 at Bandipur.

6.3.7 Nutrient leaching

In 2000 nutrient losses through leaching varied in the different terraces and cropping systems. The total loss of NO_3-N was highest from old citrus orchard (36.4 kg/ha) and lowest from young citrus orchard (8.2 kg/ha) [Fig. 6.10 a]. The loss of NO_3-N was 15.8 kg/ha from the wide-terraced maize based system and 14.2 kg/ha from the narrow-terraced maize-based system. The loss of NO_3-N in leachate was found to be highest from the old citrus orchard throughout all periods of the monsoon. The lowest leaching of NO_3-N was observed in the young citrus orchard in the early- and late-monsoon and narrow-terraced maize-based system in the mid-monsoon. The loss of NO_3-N was higher from narrow terraces than from wide terraces in the early- and late-monsoon periods. Its loss in leachate was higher from the wide terraces than from the narrow terraces in the mid-monsoon.

P loss in leachate was very low (less than 1.3 kg/ha over the whole season) [Fig.6.10 b]. Loss of P over the whole season was highest from the wide-terraced maize-based system (1.3 kg/ha) followed by the loss from the young citrus orchard (0.7 kg/ha). The lowest loss of P was observed in the old citrus orchard (0.4 kg/ha). P loss through leaching was higher from wide terraces than from narrow terraces in the early- and late-monsoon periods. However, in the mid-monsoon the loss of P was slightly higher from narrow terraces. Similarly, the loss of P was higher from young citrus orchard than from old citrus orchard in the early- and mid-monsoon periods. In the late-monsoon its loss was higher from old citrus orchard than from young citrus orchard.

The total loss of K through leaching was highest in the old citrus orchard (32.0 kg/ha) followed by the loss from the wide-terraced maize-based system (20.7 kg/ha) [Fig.6.10 c]. The loss of K in leachate was lowest from the narrow-terraced maize-based system (11.5 kg/ha). Loss of K in leachate was lower from young citrus orchard than from old citrus orchard and was lower from narrow terraces than from wide terraces in the maize-based system. Loss of K in leachate was highest from wide terraces in the early-monsoon period and highest from old citrus orchard in the mid- and late-monsoon periods. The lowest loss of K in leachate was observed in young citrus orchard in the early- and late-monsoon periods. Its loss was lowest from the narrow-terraced maize-based system in the mid-monsoon period.

In 2001 the total loss of NO_3-N was highest from the old citrus orchard (65.5 kg/ha) followed by the young citrus orchard (50.4 kg/ha) [Fig. 6.11 a]. Lowest loss of NO_3-N was from the wide-terraced maize-based system (25.9 kg/ha). The losses of NO_3-N in leachate were 45.6 and 26.6 kg/ha from the narrow-terraced maize-based system and the plot of grass planted in terrace risers respectively. NO_3-N loss in leachate was lowest from the wide-terraced plot and highest from the old citrus orchard in the early-monsoon period. In the mid-monsoon period the highest loss of NO_3-N was from the young citrus orchard followed by the old citrus orchard. Its loss was higher from wide terraces than from narrow terraces in the mid-monsoon period. NO_3-N loss was higher from narrow terraces than from wide terraces in the late-monsoon period. Grass planted in risers reduced the loss of NO_3-N in leachate throughout the early-, mid- and late-seasons.

Total loss of P was highest from the old citrus orchard (29.9 kg/ha) followed by the narrow-terraced maize-based system (0.4 kg/ha) [Fig. 6.11 b]. Lowest loss of P was from young citrus orchard (0.2 kg/ha). The amount of P in leachate was very low in all plots except the old citrus orchard. Loss of P was highest in the mid-monsoon and lowest in the early-monsoon period in old citrus orchard but it was highest in the late monsoon period in other systems.

Loss of K in leachate was highest from old citrus orchard over the whole season (398 kg/ha) followed by the narrow-terraced maize-based system (18.4 kg/ha) [Fig. 6.11 c]. Loss in leachate was lowest from the plot of grass planted in terrace risers (10.5 kg/ha). It was 12.7 and 11.9 kg/ha from the young citrus orchard and from the wide-terraced maize-based system respectively. Loss of K in leachate was highest from the old citrus orchard in all monsoon periods. K loss was higher in the mid-monsoon period than in the early- and late-monsoon periods. Loss of K was higher in the late-monsoon period than in the early-monsoon period from all plots except from the old citrus orchard where the loss of K was higher in the early-monsoon period than in the late-monsoon period.

In 2002 the loss of NO_3-N in leachate was highest from the old citrus orchard (54.9 kg/ha) followed by the young citrus orchard (48.9 kg/ha) [Fig. 6.12 a]. Loss of NO_3-N in leachate was lowest from the narrow-terraced maize-based system (29.4 kg/ha). The losses were 32.6 kg/ha and 39.8 kg/ha from the wide-terraced maize-based system and plot of grass planted in terrace risers respectively. Loss of NO_3-N in leachate was higher in the early-monsoon than in the mid-monsoon except in the case of the young citrus orchard which was higher in the mid-monsoon. The loss of NO_3-N was higher in the mid-monsoon than in the late-monsoon in all plots except in the case of the plot of grass planted in terrace risers in which higher leaching occurred in the late-monsoon period than in the mid-monsoon period.

Loss of K was highest from old citrus orchard (167 kg/ha) followed by the young citrus orchard (34.1 kg/ha) [Fig. 6.12 b]. Loss of K in leachate was lowest from the narrow-terraced maize-based system (17.5 kg/ha). The losses of K in leachate from the wide-terraced maize-based system and plot of grass planted in terrace risers were 23.6 and 18.3 kg/ha respectively. Loss of K was highest from the old citrus orchard throughout the early-, mid- and late-monsoon periods. Loss of K was lowest from the young citrus orchard in the mid- and late-monsoon periods. However, the loss of K was higher from the young citrus orchard than both maize-based systems in the early-monsoon period.

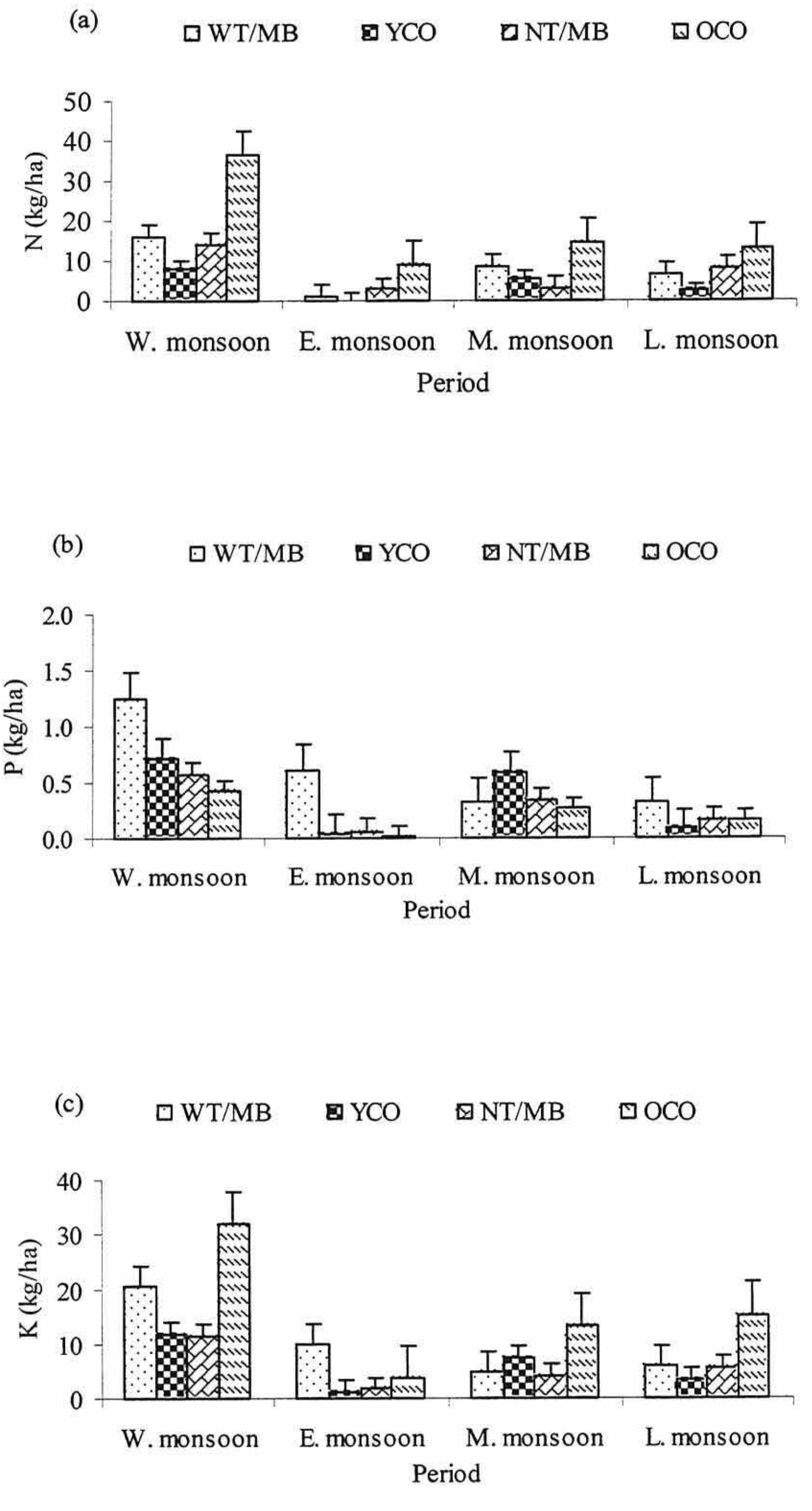


Fig. 6.10 Nutrient loss in leachate (a) NO_3-N (b) P and (c) K (Bandipur, 2000).

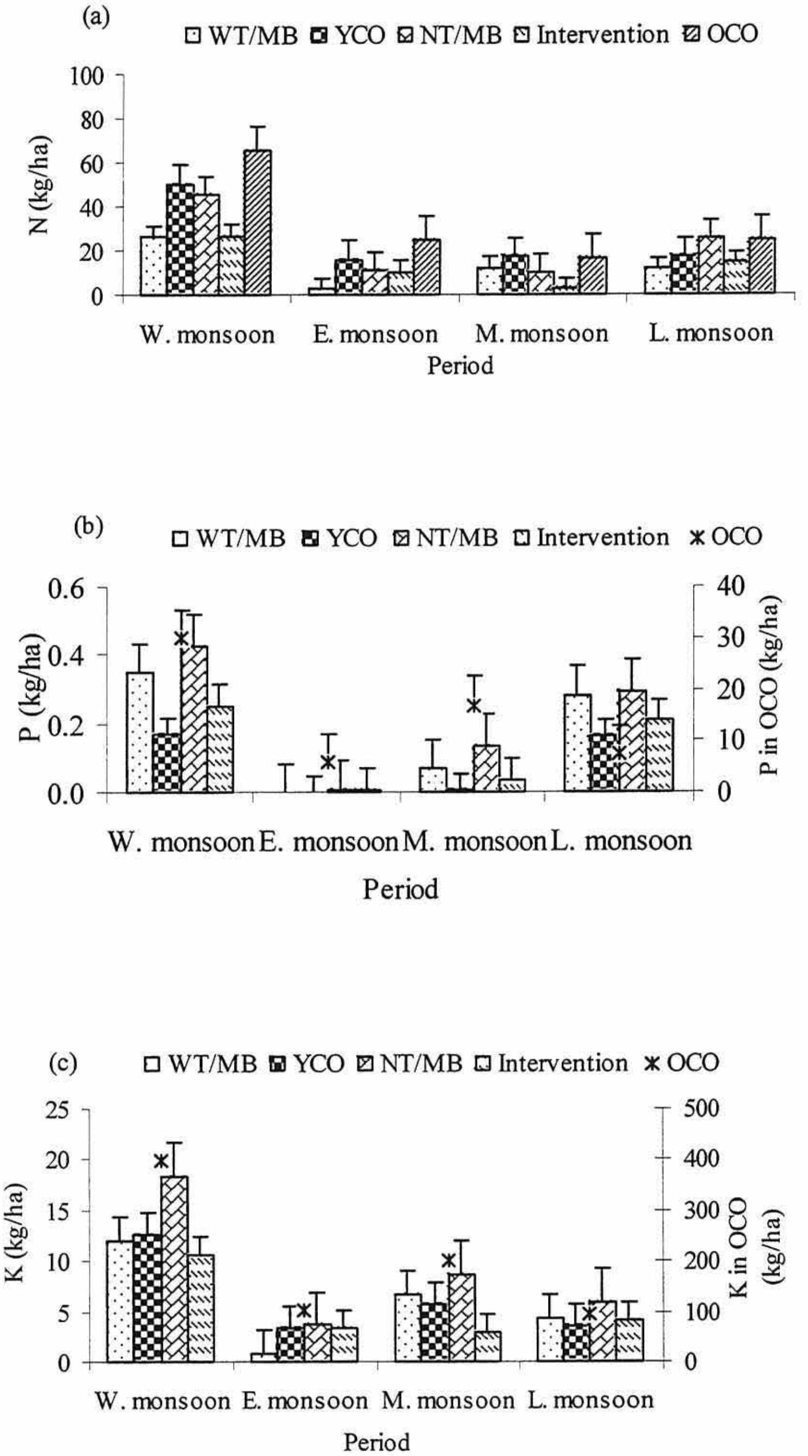


Fig. 6.11 Nutrient loss in leachate (a) NO_3-N (b) P and (c) K (Bandipur, 2001).

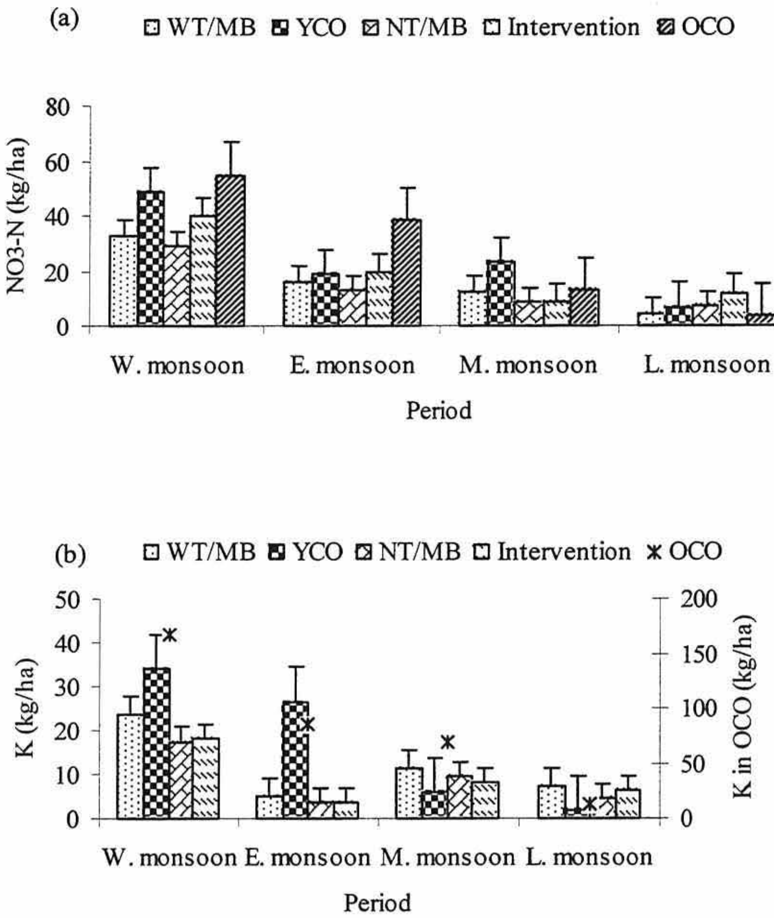


Fig. 6.12 Nutrient loss in leachate (a) NO_3-N and (b) K (Bandipur, 2002).

6.3.8 Soil fertility status after the monsoon and crop harvest

Laboratory analysis of soil samples was carried out to determine pH and organic carbon, total N, available P and exchangeable K content after the monsoon and crop harvest. CEC and soil particle size were also measured in the soil samples collected in 2002.

pH

pH was not measured in the first year's samples. In the second year pH was slightly higher in the old citrus orchard compared with other plots. Young citrus orchard had the lowest pH value. The pH value decreased slightly in all plots from 2001 to 2002. The pH value was within the acid range in all plots (Table 6.4).

Table 6.4 Effect of cropping systems on soil pH in different years (Bandipur).		
Cropping practice	2001	2002
Wide-terraced maize-based system	5.4	5.2
Young citrus orchard	5.2	5.1
Narrow-terraced maize-based system	5.3	5.1
Grass planted in risers (Narrow-terraced maize-based system)	5.3	5.1
Old citrus orchard	6.5	5.6
Mean	**5.5**	**5.2**

Organic carbon

Organic carbon content in the soil was highest in the narrow-terraced maize-based system (14.5 g/kg and 13.0 g/kg) in 2000 and 2001 and in the wide-terraced maize-based system and young citrus orchard in 2002 (Table 6.5). Organic carbon content was lowest in the wide-terraced maize-based system (7.2 g/kg) in 2000 and lowest in the old citrus orchard (7.5 g/kg and 5.5 g/kg) in 2001 and 2002. However, organic carbon content increased each year in the wide-terraced maize-based system and decreased each year in other plots. In both cases organic carbon content in the soil was lower than the bench mark value (11.3 - 14.9 g/kg). The narrow-terraced maize-based system and old citrus orchard showed a slight increase in the first year compared with the bench mark value and then started to decrease. The decrease was at a higher rate in the old citrus orchard than the young citrus orchard and narrow-terraced maize-based system.

Table 6.5 Effect of cropping systems on soil organic carbon (g/kg) in different years (Bandipur).			
Cropping practice	2000	2001	2002
Wide-terraced maize-based system	7.2	8.7	9.0
Young citrus orchard	14.3	10.6	9.0
Narrow-terraced maize-based system	14.5	13.0	7.9
Grass planted in risers (Narrow-terraced maize-based system)		11.1	6.7
Old citrus orchard	12.2	7.45	5.5
Mean	**13.2**	**10.7**	**7.6**

Total N

Total N increased in all plots each year except in the case of the old citrus orchard in which an increase was first seen in the third year (Table 6.6). Grass planted in terrace risers increased total N content in the soil in the latter year. However, all plots had a lower total N content compared with the bench mark soil sample value.

Table 6.6 Effect of cropping systems on soil total N (g/kg) in different years (Bandipur).

Cropping practice	2000	2001	2002
Wide-terraced maize-based system	0.7	1.0	1.14
Young citrus orchard	0.8	1.0	1.20
Narrow-terraced maize-based system	0.6	0.8	1.26
Grass planted in risers (Narrow-terraced maize-based system)		0.9	1.42
Old citrus orchard	0.8	0.7	0.91
Mean	**0.7**	**0.9**	**1.2**

Available P

The highest P content was found in the old citrus orchard (30.9 mg/kg) in the first year (Table 6.7). There was a large decrease in P content to 11.8 mg/kg in this plot in the second year and then an increase to 28.2 mg/kg in the third year. P content in the soil was lowest in the wide-terraced maize-based system (13.8 mg/kg) in the first year. It increased in the second year (20.4 mg/kg) and then decreased in the third year to 13.5 mg/kg. Young citrus orchard showed a steady increase in P content from 14.6 to 23.2 mg/kg over the three years. Available P increased after three years in all plots compared with the bench mark value except in the narrow-terraced maize-based system in which it decreased.

Table 6.7 Effect of cropping systems on plant available P (mg/kg) in soil in different years (Bandipur).

Cropping practice	2000	2001	2002
Wide-terraced maize-based system	13.8	20.4	13.5
Young citrus orchard	14.6	19.8	23.2
Narrow-terraced maize-based system	16.4	23.6	9.6
Grass planted in risers (Narrow terraced maize-based system)		21.4	10.4
Old citrus orchard	30.9	11.8	28.2
Mean	**18.4**	**20.1**	**15.9**

Exchangeable K

Exchangeable K content was highest in all plots in the first year (283.8 - 433.6 mg/kg) and decreased in the second year (to values from 42.8 - 84.1 mg/kg) [Table 6.8]. In the third year the highest exchangeable K content was 195.1 mg/kg in soil from the young citrus orchard followed by 160.3 mg/kg in soil from the wide-terraced maize-based system. The lowest exchangeable K content was 57.3 mg/kg in soil from the old citrus orchard. All plots had a lower K content than the bench mark value by the end of third year.

Table 6.8 Effect of cropping systems on exchangeable K (mg/kg) in soils in different years (Bandipur).

Cropping practice	2000	2001	2002
Wide-terraced maize-based system	423.5	64.2	160.3
Young citrus orchard	433.6	72.7	195.1
Narrow-terraced maize-based system	360.1	79.9	96.8
Grass planted in risers (Narrow terraced maize-based)		84.1	89.8
Old citrus orchard	283.8	42.8	57.3
Mean	**366.4**	**70.6**	**113.2**

Cation exchange capacity

The cation exchange capacity was many times lower after crop harvest in the third year than at the start of experimentation. The highest CEC was 10.2 meq/100g in the young citrus orchard and the lowest was 5.0 meq/100g in the plot of grass planted in terrace risers. The narrow-terraced maize-based system and the old citrus orchard had CEC of 5.0 and 5.1 meq/100g respectively (Table 6.9).

Soil particle size distribution

Sand content was highest in the old citrus orchard (251.5 g/kg) and lowest in the wide-terraced maize-based system. Other plots had sand content ranging from 158.5 to 191.5 g/kg. Silt content was highest in the wide-terraced maize-based system (582.8 g/kg) and lowest in the narrow-terraced maize-based system (416.4 g/kg). Clay content was highest in the narrow-terraced maize-based system (425.1 g/kg) and lowest in the old citrus orchard (298.7 g/kg). In 2002 sand, silt and clay contents (Table 6.9) were compared with values at the start of experimentation. Sand content was lower in all plots, silt content was lower in the narrow-terraced maize-based system and old citrus orchard, and clay content was higher in all plots than at the start of experimentation.

Table 6.9 Effect of cropping systems on CEC and particle size distribution in soil (Bandipur, 2002).

Cropping practices	CEC (me/100 g)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)
Cropping practice				
Wide-terraced maize-based system	8.8	77.7	582.8	339.5
Young citrus orchard	10.2	191.5	475.2	333.3
Narrow-terraced maize-based system	5.3	158.5	416.4	425.1
Grass planted in risers (Narrow-terraced maize-based system)	5.0	164.9	489.7	345.4
Old citrus orchard	5.1	251.5	449.7	298.7
Mean	**6.5**	**171.8**	**464.7**	**363.5**

6.4 DISCUSSION

Soil loss under different cropping practices at Bandipur was lowest from young citrus orchard (202 kg/ha/yr). It was highest from old citrus orchard (1316 kg/ha/yr) in 2000 and from the narrow-terraced maize-based system (1578 to 2804 kg/ha/yr) during 2001-2002. Soil loss varies in different years and different cropping systems. Soil loss may be high in a perticular system in one year and in another system in another year. Soil erodibility may change in any system over a time period. Djorovic (1990) concluded that bench terracing completely eliminates soil erosion and enables the constant use of soil on steep slopes for crop production. However, this study shows that bench terracing alone is not sufficient to reduce soil loss from sloping fields. Terracing reduces the slope angle and therefore reduces velocity of runoff but the terrace risers subsequently increase its velocity, with run-on across the risers enhancing rill erosion.

Young citrus orchard shows less runoff as most water percolates in this plot compared with other plots and hence less soil loss occurs. It was intercropped with maize and legumes. Surface cover achieved by intercropping with clover in maize fields has been found to reduce runoff (Goeck *et al.*, 1989). Establishing an appropriate vegetation cover in olive orchards has also minimised soil erosion in mountainous areas of Spain (Saavedra *et al.*, 1998). Ground cover under tree crops is found to protect the soil from the impact of water drops falling from the canopy (Morgan, 1995). The high soil loss in old citrus orchard could be due to the impact of large rain drops falling from the canopy on to the bare soil. Rainwater accumulates in the leaves and falls as large drops directly on to the bare soil (no intercrop present). The wide-terraced maize-based system shows less soil loss than the narrow-terraced maize-based system. The wide-terraced maize-based system also produces less runoff and soil loss than the old citrus orchard. Ongprasert (2002) observed that compaction of topsoil in litchi orchard reduces water infiltration and enhances runoff.

There was a larger number of terraces in the narrow-terraced plot than in the wide-terraced plot as each plot had the same net area. The plots had the same slope angle but narrow terraces lost more soil than wide terraces. The plot consisting of a higher number of terraces has more terrace risers and therefore more chance of soil loss. An increase in riser height increases the velocity of run-on and also rill erosion. The height of the terrace riser could therefore have played an important rôle in soil erosion. However, terraces having a low slope angle should result in less soil loss (Morgan, 1995).

There are a number of other factors affecting runoff and soil loss not taken into consideration by researchers and farmers. The roughness of the soil surface affects on runoff and soil loss (Helming *et al.*, 1998). The surface roughness during field preparation may vary from year to year in the same field and in different plots in the same year causing variation in soil loss within years and plots (having otherwise similar field conditions). Slope angle is the same in wide and narrow terraces but the length of the slope is longer in wide terraces. The grass planted in terrace risers acts as a barrier to both soil and water movement. Run-on passing through the grass planted terrace risers has less velocity in the risers and diverts towards percolation resulting in less soil loss than when passing through non-grass planted terrace risers. Terraces not planted with grass contain native grasses. These grasses are sometimes present as a thin population incapable of reducing soil loss sufficiently. There is a high positive correlation ($r = 0.7$) between rainfall erosivity (EI) and soil loss in the wide-terraced maize-based system and a negative correlation ($r = -0.6$) in young citrus orchard. Regression analysis shows that the relationship between KE and soil loss varies in different systems and also varies in different years in the same system. The variation in erosivity has been found to be up to 250 % in different years (Stocking, 1974). Soil loss is high when runoff is high, indicating that the soil loss will not be reduced until runoff is controlled. The control of runoff is only possible through the diversion of run-on and encouragement of rainwater to percolate. Run-on diversion has been practiced in the hills by farmers (Shrestha, 2000).

In the case of nutrient loss, a high loss of sediment gives rise to a high loss of soil organic carbon, total N and available P. These nutrients are found in quantities many times higher in sediments than in soil samples. The loss of dissolved nutrients in runoff is very low. However, old citrus orchard could lose NO_3-N, P and K in runoff to a maximum of 3.3, 0.8 and 7.1 kg/ha/year respectively. Nutrient loss in leachate is quite high with all cropping practices and it depended on the amount of water percolated through the soils. N loss in leachate was highest from the old citrus orchard (65.5 kg/ha) and lowest from the young citrus orchard (8.2 kg/ha). The amount of water percolated does not appear to be related to loss of nutrients in leachate. Leachate was higher than rainfall in most plots. This could be due to accumulated water in the subsurface layer percolating rapidly to the lysimeter. In heavy soils a hard pan between the tilled and untilled surfaces lowers the infiltration rate (Imeson and Kwaad, 1990). Accumulation of water occurs creating waterlogged conditions for short periods. Only the leachate in the young citrus orchard is within an acceptable range in the first year, and only the leachate in the plot of grass planted in terrace risers is acceptable in the third year. In the second year leachate exceeded rainfall in the old citrus orchard. The maximum N loss was 8.2 kg/ha in 2000 and 50 kg/ha in 2001 from the young citrus orchard. Gardner *et al.* (2000) reported variation in nitrate concentration between periods as well as between different plots. In 2002 the maximum N loss was 39.8 kg/ha in the plot of grass planted in terrace risers. Farmers have very little knowledge about the leaching loss of nutrients. However, these studies will make farmers aware of the problem. The District Soil Conservation Office is concentrating on soil conservation measures in watersheds and sub watersheds through people's participation (Shrestha, 2002). These selective practices could attract farmers.

CHAPTER 7

GENERAL DISCUSSION

7.1 SOIL LOSS

7.1.1 Soil Loss at Nayatola

Strip cropping (alternate strips of ginger and maize) reduced soil loss (58 - 281 kg/ha/yr) compared with the control (144 - 1756 kg/ha/yr) in which maize was grown without strips (farmers' practice) in Nayatola. Soil loss of 2 to 11 t/ha/yr can maintain sustainable crop production (Morgan, 1995). Soil losses in Nayatola are below soil formation rates. This study compares the effect of strip cropping on soil loss with the control where run-on is controlled in experimental plots. The actual soil loss could be higher in farmers' fields receiving run-on.

Mulching of the ginger strip in ginger and maize strip cropping can minimise soil loss from sloping cultivated *bari* lands. Mulching has been found to reduce runoff and soil loss (Paningbatan *et al.*, 1995; Haque, 1998; Kwaad *et al.*, 1998 and Smobilhowski *et al.*, 2001). Crop strips having mulch filter sediments allowing filtrate water into run-off and reduce soil loss to show similar results of Khera and Singh (1998). Mulching promotes aggregate stability and encourages water infiltration. Mulching of plant materials protects the soil from raindrop impact and also protects the soil from dispersion. Mulching material adds organic matter to the soil where it activates different organisms. These organisms improve the soil's physical and chemical structure. Organically formed soil may be less susceptible to erosion (Siegrist *et al.*, 1998).

There is less tillage in ginger strips compared with maize because farmers mound the soil around maize plants during growth periods. Tillage contributes to the total soil loss (Turkelboom *et al.*, 1997). Tillage erosion rates in the upland region of northern Thailand ranges from 8 - 18 t/ha/yr. Reduced tillage has also contributed to minimise soil loss by improving the physical properties of the soil (Tebrügge and Düring, 1999). Similarly ginger and maize strip cropping enhances water infiltration rate and reduces runoff and soil loss.

Maize and legume strip cropping (alternate strips of maize and legume) has also been shown to reduce soil loss. However, the selection of a suitable legume crop is problematic. The existing legume crop is soybean. This is different to maize in its soil fertility level requirement and performs satisfactorily at a low level of soil fertility. Other existing legume crops in the area are cowpea, field bean and rice bean. These have indeterminate types of plant growth and weak stems. They are grown with maize as a mixed crop. Research has shown that soybean cultivation can minimise soil erosion. A rotation of maize and soybean with reduced tillage decreases soil loss to a level below 7.8 t/ha/yr (the soil loss tolerance limit for crop production) [Shipitalo and Edwards, 1998]. If the maize strips are exchanged for soybean strips in the following year, strip cropping of maize and soybean can be more beneficial. Soybean cultivation without tillage results in very low runoff and soil loss (Ghid, and Alberts, 1998). Weed growth is greater when tillage is not performed; the soil cover by weeds reduces runoff and soil loss (Bertol and Fischer, 1997). However, weeds need to be controlled in order to reduce their effect on crop yield. The legume strips require minimum tillage compared with maize under the existing farmers' practice. Legume crops are used as cover crops (to reduce the erosive effect of raindrop impact on soil) and as N fixers contributing to an increase in soil N. Most legume crops are deep rooted. The deep root system improves the micro-porosity of the soil which results in better infiltration and less runoff (Morgan 1995). The plants grow rapidly and the canopy develops in a short period and suppresses weeds.

However, more than 75 % of soil loss occurs in the early-monsoon with only a few rainfall events. A great variation occurs in the erosive force of rainfall resulting in a variation in soil loss from year to year (Stocking, 1974). Most events causing soil loss occur early in the season even if rainfall is less per event. A higher soil loss occurs in early periods because weed surface cover has not developed fully (Stocking and Elwell, 1973). Vegetative cover plays a key rôle in rainwater conservation. The vegetative covers of 13.1, 48.3, 60.9, 69.2 and 83.1 % produce sediments of 9.3, 5.9, 2.1, 0.1 and 0.03 t/ha/yr respectively in hilly red soil regions of China (Jianguo and Chacha, 2002). There is also a negative correlation between soil erosion rate and vegetative cover and a positive correlation between soil erosion rate and slope. An increase in slope by 1° increases soil erosion by 1.2 t/ha/yr.

Frequent rainfall even with low magnitude rainstorms of less than 10 minutes duration contributes to a more sustained sediment movement (Chatterjea, 1998). This is because the first intensity rainstorm increases the sediment generating potential on bare surfaces to the incoming rainfall. Gardner *et al.* (2000) have mentioned that, in Nayatola, soil conservation practices are not always important but that an extreme event may occur within a 5-6 year interval. Erodibility of a soil can change with time due to exposure of subsoil which might have different properties than the surface soil (Lal and Elliot, 1994). Farmers therefore need to continue protective cultivation, employing the least expensive soil conservation technologies.

7.1.2 Soil loss at Landruk

Amongst the different agroecological sites soil loss ranged from 886 to 7256 kg/ha/yr in the control at Landruk (2000-2002). The lowest soil loss was in 2001 even though the annual rainfall was highest in this year. The slope angle of cultivated sites is greater than 20° in Landruk.

There is substantial soil loss from high rainfall bench terraced areas. However, soil loss is quite low compared with other erosion prone countries. High rainfall intensity in hilly areas produces a relatively higher amount of soil loss (Kurothe *et al.*, 2001).

Run-on diversion above the terraces reduces soil loss under steep slope conditions (Morgan 1995) because it reduces the velocity of water reaching terraces and hence minimises soil erosion (especially rill and gully erosion). Erosion starts with sheet erosion in which raindrops detach soil particles and accumulated water starts to move downslope carrying soils whereas run-on enters the field and starts to form rill or gullies (depending on the amount and velocity of run-on). Sheet erosion produces less sediment than rill and gully erosion.

Grass planted in terrace risers reduces runoff and soil loss later in the year once the grass has established. However, the planting operation can accelerate erosion. Grass planted in the riser acts as a grass strip between two terraces, reducing soil loss from runoff (Lewis and Nyamulinda, 1996). Broom grass planted in terrace risers reduced soil loss by 22 % in the mountain farming system of Sikkim (Sharmmfl *et al.*, 2001). Intercropping and grass strips are more economically attractive to farmers compared with hedgerows as the latter involves more establishment and maintenance costs (Nelson and Cramb, 1998). Changqing *et al.* (2002) observed that total soil loss over the season from a grass (Bahia) planted field was 0.12 t/ha/yr compared with 125.56 t/ha/yr in bare fields having red soil on hilly sloping land. Erosion has been reduced in south China (where torrential rainfall erodes the deeply weathered and denuded granitic hills) by the use of soil conservation techniques (Sheng and Liao, 1997). Stone bunds at 15 m spacing reduce runoff and soil loss compared with the control (Okoba *et al.*, 1998). Soil at Landruk is more susceptible to erosion than the soils at Nayatola and Bandipur. The former contains a dominance of sand particles making it susceptible to erosion (Bhushan *et al.*, 2002). Mawdesley *et al.* (1998) found Landruk to be highly susceptible to runoff and erosion.

For centuries mountain farmers have been practicing various indigenous technologies which minimise soil erosion (Changkija, 1997). Amongst the important technologies are bench terracing, intercropping of legumes with maize, and mixed cropping. Bench terracing enables the cultivation of steep hillsides and reduces soil erosion (Critchley *et al.*, 2001; Chen-Bo and Lingqin, 2002). Terracing of steep slopes results in a large number of terraces having a narrow width and taller risers. The use of conservation tillage varies between crops and is dependent on site-specific factors including soil type, topsoil depth and local climatic conditions (Uri, 1998). Narrow terraces suffer more soil loss as the slope length of individual terraces is short resulting in greater soil runoff loss (Lal, 1997).

7.1.3 Soil loss at Bandipur

There is a diverse range of cropping systems in Bandipur. Each system shows a different magnitude of soil erosion. Less soil loss occurs in young citrus orchard in which intercropping is practiced. Crops used in intercropping cover the soil surface and protect the soil from the impact of water drops falling from the citrus canopy. In addition, legume intercrops add fertility and organic matter to the soil thereby improving soil structure. Soil organic matter improves aggregate stability and helps to reduce runoff and soil loss (Rhoton *et al.*, 2002). It also encourages water infiltration and minimises soil detachment.

Old citrus orchard shows a higher soil loss than young citrus orchard. Runoff occurs due to compaction of soil and decrease in the infiltration rate. The citrus canopy without an intercrop results in water droplets of a large size falling on bare land causing greater sheet erosion. Permanent woodlands with surface grass cover have less chance of high erosion (Bissonnais *et al.*, 2002). Land covered by shrubs produces low sediment (De Luis *et al.*, 2003). Based on soil type citrus orchard is the most suitable crop for Bandipur. Citrus orchard combined with intercropping minimises soil loss. There is reduced tillage or no tillage in citrus orchard therefore it increases water infiltration and decrease runoff until soil compaction develops. Old citrus orchard is remained fallow for a long period and developed compaction in soil resulting in higher soil loss compared with young citrus orchard. Intercropping in citrus orchard is a less eroded practice to be promoted in other areas.

Soil loss is low in the sloping land cultivation system compared with the bench terracing cultivation system. Slope angle of the terraces has less effect on soil loss. Surface cover (grass), erosive rainfall, soil aggregate stability, cropping system and general slope of the area are factors affecting soil erosion from cultivated fields. The middle mountains of Nepal consist of limestone, dolomitic shale, sandstone, slate and quartzite (Carson *et al.*, 1986). Due to the nature of the soil forming material, steeply sloping areas are more susceptible to soil erosion than gently sloping areas. A few small events can cause very high soil loss. Soil in Nayatola and Bandipur contain higher amounts of clay but the clay type may be different in Bandipur from that in Nayatola. The presence of kaolinite in soil results in high aggregate stability, minimising soil detachment and transport whereas the presence of montmorillonite in soil results in low aggregate stability, causing high runoff and therefore more soil loss (Wakindiki and Ben-Hur, 2002).

Soil loss occurs generally in the early-monsoon period in the middle hills. Crop planting and growth stages of the crop are delayed when rain occurs late. There is no runoff and soil loss until soil is saturated with rainwater even if soil is bare. Cover, canopy and tillage differ based on crop stages and these determine soil loss at a particular period of the year (Mutchler *et al.*, 1994). The type of crop is most important factor in soil conservation because it can be managed to reduce erosion (Renard *et al.*, 1994). Soil characteristics and erosive rainfall contribute to soil loss in various agroecological regions.

7.2 NUTRIENT LOSS

7.2.1 Loss of organic carbon

Organic carbon loss in sediment varies in different sites and years. Landruk lost the most organic carbon followed by Nayatola and then Bandipur. Strip cropping in Nayatola reduced carbon loss by 41 - 79% compared with the control. Run-on diversion and grass planted in risers in Landruk reduced organic carbon loss by 48 – 54% compared with the control. In Bandipur young citrus orchard lost less organic carbon than old citrus orchard and wide terraces lost less than narrow terraces. Strip cropping has reduced soil and its organic carbon losses. Because ginger and legume strips have reduced tillage compared with control in which intense cultivation creates oxidative soil environment to decompose organic matter fast resulting additional carbon loss from the soils (Halvorson *et al.*, 2002). Land remains fallow for long time in old citrus orchard to develop hard pane and prevents water infiltration. It causes high runoff and soil loss of higher organic carbon than the soil loss from young citrus orchard.

7.2.2 Loss of N

N loss is mainly associated with leachate in all sites. Leachate NO_3-N content was higher from Nayatola than from Landruk. Leachate from Bandipur contained the lowest N content. The total amount of N lost from the field varies from year to year and from site to site and may be due to differences in FYM application. Intervention either did not affect or increased N loss especially through leaching.

Mulch applied to ginger in the ginger and maize strip cropping reduces NO_3-N concentration in leachate compared with that of the control. However, it enhanced higher amount of water infiltration and therefore resulting in high loss of NO_3-N leaching. A mulched tillage system yields less nitrate but the extent of leaching may be site-specific (Kitchen *et al.*, 1998). NO_3-N content of leachate from citrus orchard is higher than that from the cereal crop (maize based). Deep rooted crops followed by minimal cultivation may initiate for less NO_3-N leaching compared with shallow rooted crops and intensive cultivation. NO_3-N leaching varies depending on the management. There is a high probability of N loss from the soil with farmyard manure application in the field. Hollinger *et al.* (2001) observed a high concentration of N in runoff after poultry manure application. However, Stoper *et al.* (2002) found that NO_3-N leaching was lower in organic farming (47 kg/ha/yr) than in conventional farming (58 kg/ha/yr) in which inorganic N inputs were used. Use of an appropriate method of manure application could minimise N loss from fields.

7.2.3 Loss of available P

Available P content is many times higher in eroded sediment from all sites compared with P in the soils. P is not lost in significant quantities as dissolved P in water from any sites. However, its concentration in eroded sediment is high and quantity depends upon the amount of sediment loss. Soil erosion is the major mechanism for P mobilization and transport (Hollinger *et al.*, 2001). P becomes less available due to formation of iron and aluminium phosphate at pH below 5.5 and calcium phosphate at pH above 7. Due to a high absorption rate in the middle hills of Nepal, P hardly dissolves in water and therefore less is lost in runoff and leachate. P absorption rate in soils was found to be high (soil sample analysis in SAFS soil laboratory) in three research sites (Fig 7.1).

However, variation in P absorption exists from farm to farm due to different management practices. P adsorption is correlated to soil clay content (Moughli *et al.*, 1992). The high soil clay content might account for the lower availability of P in the water extract (runoff and leachate) at the sites (especially Nayatola and Bandipur). Bare uncultivated soil in the old citrus orchard produced sediment with a high P content compared with other cultivated terraces. P content was also highest in leachate from old citrus orchard. P adsorption is lowest in the soil from old citrus orchard compared with other plots. Wallbrink *et al.* (2003) found a low P content in cultivated soil possibly due to the export of P with crop materials in cultivated land. Bray-P could not be lost more than 3.7 kg/ha in runoff and its loss could be 20 kg/ha/yr with sediment (Lal, 1993).

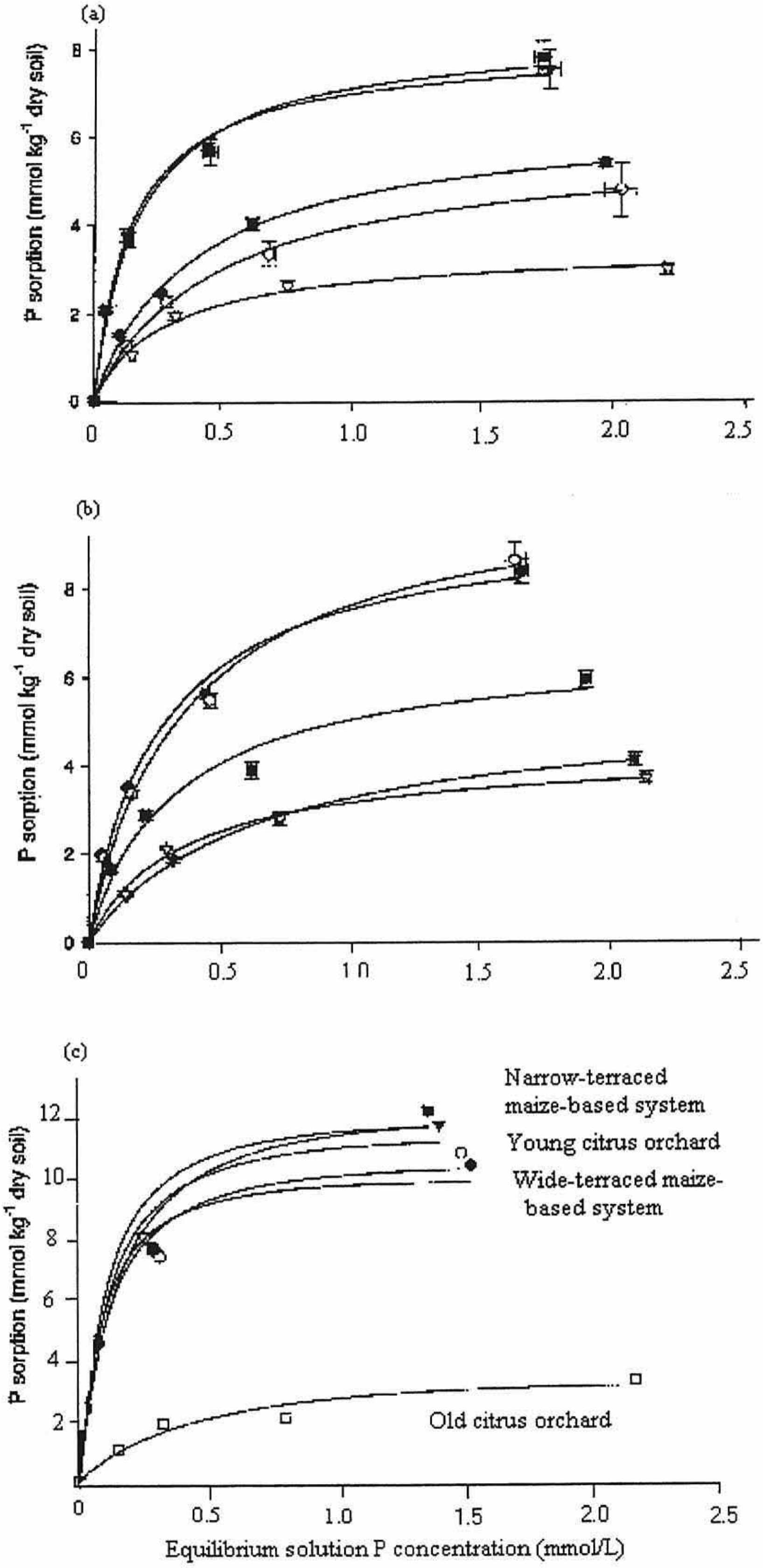


Fig. 7.1 P sorption in soil at different sites (a) Nayatola, (b) Landruk and (c) Bandipur.

7.2.4 Loss of K

Like N, K loss is also associated mainly with amount of leachate in all sites. K content was higher in the leachate from Nayatola than from Landruk. Leachate from Bandipur contained the lowest K content. The total amount of K lost from the field varies from year to year and from site to site. Interventions either did not affect or increased K loss (especially through leaching) except in the plot of grass planted in terrace risers at Landruk. Grass planted in risers tends to reduce K loss through leaching. *Setaria aneps* planted in terrace risers takes up more K thereby reducing its loss. The soil samples from Nayatola and Bandipur contain a greater proportion of clay than the sample from Landruk. This might have an effect on the K content of runoff and leachate. However, old citrus orchard in which cultivation was not performed tended to have an increased K content in leachate. Amongst the nutrient elements K is the most susceptible to leaching (Silfverberg, 1998). As with NO_3-N its concentration is lower in the leachate from maize and ginger strips compared with that in leachate from the control but total K loss is greater in maize and ginger strips because of greater leachate amount than in the control. If infiltration rate decreases as rainfall intensity and its kinetic energy increases sealing soil pores, hence K leaching decreased (Shainberg *et al.*, 2003 ; Wang *et al.,* 2002). However, it depends on soil type; K loss is higher in high rainfall areas compared with low rainfall areas in the middle hills of Nepal.

N and K loss in leachate is mainly caused by water percolation, especially in mulched cropping systems or from reduced cultivation systems (e.g. legume intercropping or orchard). Water stable soil aggregates decrease in continuous corn fields and increase from 23 % to 40 % in the field when legumes are grown in rotation (Rachman *et al.*, 2003). In intercropping systems water stable aggregates may be present in high quantities in the surface soil and enhance leaching (Kumar *et al.*, 2002). Aggregate stability is reduced in the surface soil due to frequent wetting and drying of the upper surface (Rachman *et al.*, 2003). Moreover, frequent tillage and expose to raindrop impact during the fallow period may increase disruption of soil aggregates. High leaching of K from old citrus orchard could be the result of the presence of uncultivated soil to enhance infiltration rate. However, land left bare and fallow results in an increase in organic matter mineralisation and nutrient leaching (Ruszkowska *et al.*, 1993). Increased diversity in agriculture (especially in terms of crops and cropping systems) can help to minimise nutrient leaching loss (Main *et al.*, 1999). This is possible in Bandipur and Nayatola but the choice of crop and cropping system in Landruk is restricted particularly in the rainy season.

Plant nutrient losses from cultivated land are undesirable. The routes by which losses occur are dependent on the type of nutrient. Most N and K are lost through leaching. N loss also occurs through volatilization and denitrification. NPK and organic carbon losses are high in agriculture soil (McDonald *et al.*, 2002). Agricultural lands receive nutrients externally and nutrient residues are lost along with soil. The quantity of sediment and nutrient concentration determine the total amount of nutrients lost by erosion. Nutrient losses vary with the amount of soil loss, runoff and leachate and result in degradation of land and economic loss for farmers. The majority of nutrients are lost with sediment and in leachate in the middle hills.

7.3 SOIL FERTILITY AND CROP PRODUCTIVITY

Significant amounts of the major nutrients (e.g. N and K) are lost in leachate. Farmers supply nutrients through application of FYM. Nutrient content of FYM may vary depending on the bedding materials utilised and type of livestock. The amount of FYM applied depends on its moisture content. Nutrient supply varies from farm family to farm family, area to area and year to year. The amount used in one year was twice that used in another year (30.4 and 15.2 t/ha in two consecutive years). The nutrient content of FYM was high in Nayatola and Landruk. Brown *et al.* (1999) who reported low nutrient content in FYM in farmers' fields in the Jhikhu khola watershed areas.

The highest soil N content was in the ginger and maize strip cropping plot. P and K contents were higher in the maize and legume strip cropping. K content was lower in the ginger and maize strip cropping plot in 2002. In Nayatola total N was lower in the control and slightly higher in interventions compared with the initial value. These results indicate that strip cropping of maize and ginger or maize and legume crops improves soil N content. Decomposed mulching material increases soil N content in the maize and ginger strip cropping system. In the maize and legume system the legume crop fixes atmospheric N, adding it to the system.

The soil carbon content is slightly higher in the latter year of experimentation than the initial value. However, its content varies from year to year. The variation in C content in the soil might be due to variation in the amount of residue left in the field and the amount of FYM applied. The amount of sediment lost also varies from year to year, affecting soil organic carbon content. The decreases in soil profile depths and nutrient stocks results soil degradation (Hopkins *et al.*, 2001).

Neither maize and ginger strip cropping nor mulching with plant material appear to have an effect on soil available P content but maize and legume strip cropping increased soil P content. This indicates that the use of plant material does not improve soil P content. There might be differences in uptake of P by crops. Ginger may take up more P from the soil. However, all plots had a raised soil P content compared with the bench mark value. The status of available P in soil may vary depending on crop yield, a high yield could mean a reduction in the soil P content.

Maize and ginger strip cropping has a direct effect on productivity. Application of a mulch of grass to maize fields resulted in high maize grain yields (Katiyar, 2001). The soil NPK balance in the maize and legume strip cropping was satisfactory. However, the uptake of NPK by the maize and ginger strip cropping is greater and therefore requires better management for a sustainable crop yield.

Organic carbon loss from the control plot was higher than from the closed plot throughout the experimental period However, no improvement in soil organic carbon content was observed. This might be due to a low rate of FYM application in combination with carbon loss via other routes. The loss of dissolved carbon in leachate and runoff was not measured in this study. Farmers do not apply a constant amount of FYM each year. In Landruk more FYM was applied in 2001 than in 2002. The direct contribution to soil fertility during *in situ* manuring by cattle and goats was not measured. More time was available for *in situ* manuring of the maize crop (followed by barley) than the maize/millet crop. The duration of *in situ* manuring in different plots in different years may cause variation in soil nutrient content.

Soil N content decreased in all plots compared with the initial values. The amount of FYM applied and the soil carbon content generally determine the soil N content unless the C : N ratio in the soil is changed. The N content was higher in the closed plot than other plots possibly due to less loss of dissolved N in leachate. Soil P content was also less than the initial value and decreased in subsequent years. Soil P content was unaffected by intervention. P adsorption is higher in red soil compared with non red soil (Schreier *et al.*, 1999). Nayatola and Bandipur soils are red in colour and have less available P than Landruk soils. Soil K content decreased to below the bench mark value. The contribution from rain, FYM application and crop residues in the field varies from year to year, bringing changes in NPK content and soil organic carbon content. Soil CEC was not affected by intervention but it was lower than the initial value. Amongst the soil particles, sand decreases and silt and clay increase compared with the initial value but the rate is lowest in the closed plot and grass plot. This indicates that sand particles are more sensitive to erosion than silt and clay particles.

Interventions show the increase maize yields which might be due to reduction in top soil loss. Khoshoo and Tejwani (1993) reported that removal of 2.5 cm topsoil decreases maize grain yield by 14 %. However, the effect of soil loss on crop yield depends on the depth of soil. Crop yield will not be affected for 200 years if the soil depth is 2 metres even if soil loss is 25 t/ha/yr (Arden-Clarke and Evans, 1993). Climatic change from year to year does not have a measurable effect on the level of erosion severity or on crop productivity (Arriaga and Lowery, 2003). The benefit cost ratio increases only in the long run after the introduction of soil conservation practice (Ashok and Ramasamy, 2002). Dwivedi *et al.* (2003) reported that cowpea minimised NO_3-N leaching beyond 45 cm depth in the soil profile when it was planted as a forage crop before rice. Cowpea removed a greater amount of nutrients via the above ground biomass than that recycled through roots and nodules, resulting in less nutrient leaching. Nutrient leaching depends on a numbers of factors including type of crop, soil and management practice.

The red soils at Nayatola and Bandipur are lateritic and suitable for horticultural crops (Sivasankaran *et al.*, 1993 and Pandey *et al.*, 1998). Bandipur already has pocket areas of citrus cultivation and farmers in Nayatola are turning to citrus cultivation. However, these red soils tend to be more susceptible to erosion.

A substantial amount of nutrients is added to soil via rainfall. Loss of soil from uplands (*bari* land) due to runoff benefits the *khet* lands by adding fertility (Grosjean *et al.*, 1995).

Farmers apply a large quantity of farm yard manure to *bari* land than khet land. Estimates of NPK balance in upland are negative for N (-21 kg/ha/yr), positive for P (12 kg/ha/yr) and positive for K (37 kg/ha/yr) in the Pokhara area. In Nayatola N balance is only negative under high yield production in maize and ginger strip cropping. In Landruk all NPK balances are negative except N from run-on diversion. However, nitrogen denitrification and volatilization are not measured at these sites. The loss of N may not be greater than 13-18 kg/ha/yr through denitrification and 15-25 kg/ha/yr through volatilization (Allingham *et al.*, 2002). Farmers apply N to *bari* land mostly through FYM which may not lose much N through denitrification and volatilization.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions drawn from the three years research into soil and water conservation in the middle hills of Nepal. Research was conducted at Nayatola, Palpa (a site representative of sloping *bari* land having low to medium rainfall), Landruk (a site representative of the bench terracing system having high rainfall) and Bandipur (a site representative of citrus pocket cultivation and diversified cropping systems). Some recommendations are proposed for the promotion of soil conservation practices and potential areas for future research are also outlined.

8.1 CONCLUSION

8.1.1 Soil and nutrient management on sloping *bari* land

Results of strip cropping experiments in Nayatola showed that maize and ginger strip cropping reduces runoff and soil loss. Maize and ginger were planted in alternate strips across the slope in the sloping terrace. A mulch of plant material was used in the ginger strips. These strips created a barrier minimising runoff and soil loss from sloping bari lands. More than 75% of annual soil loss occurs in the early season (before 15th June) in which runoff was 8% of the rainfall in the control plot. Maize and ginger strips reduced annual soil loss 3-6 times compared with the control (maize grown without strips).

Ginger cultivation is common on most hills of the western region. Farmers can therefore practice strip cropping of maize and ginger, adopting it in their sloping bari lands. Ginger cultivation provides short-term benefit to farmers compared with cultivation of maize alone. However, it cannot be grown on a large scale as there is not much scope for ginger marketing in remote areas. Moreover, as the area under ginger cultivation increases, there is a greater requirement for mulching material.

Alternatively, maize and legume strip cropping can be employed. Farmers grow different legumes as a mixed crop with maize. Amongst the legumes soybean is a suitable crop for strip cultivation. It minimises soil erosion greatly and improves soil fertility by fixing atmospheric nitrogen. Maize and soybean strip cropping reduced soil loss compared with the control. Soybean is a very good cover crop and increases soil fertility in marginal lands. However, local genotypes do not perform satisfactorily on all types of land especially in highly fertile soil.

Strip cropping of maize and ginger or soybean reduced the loss of organic matter and hence the loss of nitrogen. Organic carbon loss in sediment ranged from 8.5 to 56.9 kg/ha/yr in the control at Nayatola. Ginger and maize strip cropping can reduce this loss to 1.1 - 15.2 kg/ha/yr and legume and maize strip cropping can reduce it to 13.2 - 29.4 kg/ha/yr. However, loss of NO_3-N is higher from intervention plots than from the control plot because of higher amounts of water percolation from intervention plots. Loss of K was not affected by interventions. There was a lower K content in leachate than in runoff. In addition, a high proportion of clay particles in the soil held N and K in the soil reducing their leaching.

8.1.2 Soil and nutrient management in bench terraced high rainfall areas

Landruk is a sensitive site due to the steepness of the slope on which its terraces are formed. The terraces are narrow and have a short slope length leading to high erosion. The total annual rainfall is high and there is therefore opportunity for erosive rainfall events to coincide with soil cultivation work. Soil in Landruk contains a high proportion of sand. This enhances soil erodibility.

Results of the experiments conducted at Landruk confirm that diversion of run-on reduced runoff to 4.7 - 8.83% from 5.6 - 11.3% and soil loss to 478-4653 kg/ha/yr from 886 – 7256 kg/ha/yr in the control (in which run-on is not controlled). Bench terraces have less than a 5° slope angle. The steepness of the general slope gives a substantial height to the terrace risers. The height of the terrace riser contributed to soil loss from the terrace because the velocity of run-on through the riser entering the terrace causes rill erosion. The reduction in soil loss resulted in a reduction in loss of organic matter from the fields. However, leaching of N and K were hardly affected.

Grass planted in terrace risers enhanced water infiltration and acted as a barrier to soil movement. It ultimately reduces soil loss when complete establishment results in coverage of the whole risers. In the first two years grass establishment was poor in risers. The planting and replanting operations increased runoff and soil loss compared with the control. *Setaria aneps* is a suitable grass species for adoption in risers at Landruk. Farmers are satisfied with this species as it is palatable for farm animals. In the latter year it reduced loss of organic carbon to 82.6 kg/ha from 182.1 kg/ha in the control plot. Leaching of N was not affected and K in leachate was reduced by grass planted in risers compared with the control. The reduction in K leached might be due to its higher uptake by the grass planted in risers. Laboratory analysis confirmed higher K uptake in *Setaria aneps* compared with native grass.

8.1.3 Soil and nutrient management in pocket areas of citrus cultivation and maize-based terraces

Low soil loss (163 – 269 kg/ha/yr) was observed in young citrus orchard compared with old citrus orchard (652 – 1316 kg/ha/yr). Intercropping is main reason for a reduction in soil and nutrient loss from young citrus orchard. Farmers grow cereal or legume crops under the citrus orchard until the citrus plants are fully grown. A legume intercrop acts as a cover crop and protects the soil from raindrop impact. The loss of nutrients in leachate was also lower in young citrus orchard (8.2 - 50.4 kg/ha/yr NO_3-N and 11.7 – 34.1 kg/ha/yr K) compared with old citrus orchard (36.4 – 65.5 kg/ha/yr NO_3-N and 32 – 399 kg/ha/yr K).

Narrow terracing is more susceptible to soil loss compared with wide terracing in the maize based system. Wide terraces lost less soil (221 – 745 kg/ha/yr) compared with narrow terraces (812 – 2804 kg/ha/yr). Planting of *Setaria aneps* in terrace risers also reduced soil loss (844 - 2095 kg/ha/yr). There was no clear difference in the leaching losses of N and K between wide and narrow terraces. Grass planting in risers did not affect nutrient leaching.

8.2 RECOMMENDATIONS

8.2.1 Technology promotion and adoption

Crops are grown on the basis of farmers' needs, type of land and management skills. The maize-based system is common in all *bari* lands of the middle hills. The cultivation of ginger in combination with the mulching practice is found to reduce soil erosion considerably in the sloping cultivated *bari* lands. It can be practiced by farmers on land most prone to soil erosion. It improves the soil's physical condition and soil N content after decomposition of the mulching materials and mineralisation. Existing farming systems vary within a small area in terms of the management and constraints of resources.
Soybean strips alternating with maize strips across the slope reduce soil erosion in the sloping bari lands. Soybean yields are better on marginal lands than fertile land. Marginal land is highly susceptible to soil erosion. These soybean strips require less tillage compared with maize and therefore soybean strips act as a soil movement barrier and their canopy covers the ground, minimising the raindrops' impact on bare soil. The soybean crop fixes atmospheric N and increases available P in the soil by enhancing microbial activity. Thus it improves soil fertility.

Diversion of run-on in combination with grass planted in terrace risers minimises further soil loss from the bench terraced system especially under high rainfall conditions. Diversion of run-on conserves a large amount of organic matter and soil nitrogen in the bari lands. Grass planted in terrace risers recycles a portion of nutrients that would otherwise be lost.

Citrus orchards must be intercropped in order to minimise soil erosion. Intercropping protects bare soil from sheet erosion under the citrus canopy. The citrus canopy has the effect of increasing raindrop size and this, in combination with the bare soil condition, could encourage soil erosion.

National policy should promote and extend these technologies to the relevant areas by providing incentives and technical support to the farmers.

8.2.2 Constraints for technology promotion and adoption

In the short-term the effect of intervention on soil properties is not clear but the change from bench mark values in the control indicated that there was an effect as a result of other factors on soil properties over time. The skill of farmers in managing the sale of ginger, available mulching material and crop stripping in the terraces are management constraints affecting the adoption of available technology.

Farmers should be aware of the diversion of run-on from crop fields to the permanent waterways. This is only possible if organizations encourage farmers and provide funds for its implementation.

There is a limited number of grass species suitable for growth in terrace risers. Native grass only grows after soil loss has been lost from the terraces in the mid-monsoon season. Fast growing grass species are required for riser planting in order to ensure minimal soil loss in the early-monsoon season through quick establishment.

If the maize based system is restricted to wide terraces and citrus orchard covers all the narrow terraces, soil and nutrient loss could be reduced. Farmers usually intercrop citrus orchard with cover crops. In sloping areas most of the terraces are narrow so the risers need to be planted with fast growing grasses to minimise soil loss.

8.2.3 Further research for improving soil and nutrient management in the middle hills

Field research is needed to identify additional crops suitable for cultivation in strips with maize in the sloping *bari* land.

Studies on the effect of maize and ginger strips without mulch in relation to soil conservation and crop yield may help in increasing areas under maize and ginger strip cropping. There is a lack of information about other crops more tolerant to erosion which could be employed in strip cropping.

Further study of grass species should be carried out in terrace risers to identify those species best suited to particular areas. Research should continue for at least 5 years as grass establishment takes more than 3 years after which the grass can have an effect on soil and nutrient conservation.

Other cropping systems tolerant to soil erosion such as alley cropping, hedgerows of fruits, and fodder crops should be continued in the Palpa district and should be promoted in other areas. Farmers must be provided with a number of technology options. Individual farmers have different requirements and technologies may not be adopted if they are too limited.

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APPENDICES

Appendix 3.1 (a). Model of ANOVA for data analysis of the experiments laid out in randomised complete block design at Nayatola.

Source of variation	DF
Rep	4
Treat	2
Error	8
Total	14

Appendix 3.1 (b). Model of ANOVA for data analysis (on soil properties) of the experiments laid out in split plot to find out interactions between treatments and plot positions at Nayatola

Source of variation	DF
Rep	4
Treat	2
Residual	8
Plot position	2
Treat.Plot position	4
Residual	24
Total	44

Appendix 3.1 (c). Model of ANOVA for data analysis of the experiments laid out in randomised complete block design to find out interactions between treatments and cropping systems at Landruk.

Source of variation	DF
Rep	3
CS	1
Treat	2
CS.Treat	2
Residual	6
Total	14

Appendix 3.1 (d). Model of ANOVA for data analysis (on soil properties) of the experiments laid out in split plot to find out interactions between cropping systems, treatments and plot positions at Landruk.

Source of variation	DF
CS	1
Rep	3
Plot position	2
CS. Plot position	2
Residual	6
Treat	2
CS.Treat	2
Plot position. Treat	4
CS. Plot position.Treat	4
Residual	18
Total	44

Appendix 3.1 (e) Model of ANOVA for contrast analysis to compare intervention with control and interventions to each other.

Source of variation	DF
Rep stratum	4
Treatment	2
Contrast 1 (control/intervention)	1
Contrast 2 (between interventions)	1
Residual	8
Total	14