THE NUTRIENT STATUS OF SOILS IN SHENCHONG BASIN

THE NUTRIENT STATUS OF SOILS IN SHENCHONG BASIN AND THE EFFECTS OF SOIL EROSION

By

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ABSTRACT

The nutrient status of the soils in Shenchong Basin and the effects of soil erosion were examined during the summer of 1987. Eight raingauges and two thermographs provided meteorological data. Soil samples were collected from different land use categories in the uplands and lowlands, including agricultural areas. Water and sediment samples were collected from 1) surface discharge from the upland slope, rills and a gully during storms and 2) surface and ground waters during dry weather. Analysis was carried out on water samples to determine ammonia-nitrogen, nitrate-nitrogen, orthophosphate, soluble iron, calcium and potassium concentrations. The soil and sediment samples were analyzed for nitrate-nitrogen, available phosphorus, exchangeable potassium, calcium, magnesium and iron.

Concentrations of nitrate and orthophosphate in the water samples were very low. Potassium showed the highest concentrations. Ammonia was the dominant inorganic nitrogen species in water and possibly the soils.

The soils were highly acidic (pH < 5) and the soluble iron concentrations were high in the upland soils. Total aluminum concentrations were also high. Potassium concentrations were high in soils from vegetated areas. The higher levels of calcium and magnesium in the agricultural soils were were related to lime

additions. Available phosphorus concentrations were very low. Nitrate showed no spatial trend except for the high concentration in the cassava field which was attributed to the peanut plants that were previously planted there. In general, nutrient concentrations were low compared to other tropical areas in the world.

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CHAPTER 1

INTRODUCTION

1.1 Background

Soil degradation is one of several serious environmental problems facing China today. Soil degradation is defined as a process which lowers the current or potential capabilities of the soil to produce goods and services (FAO,1979). This can be brought about by soil erosion, chemical degradation and physical degradation. In the granitic areas of South China, the unfortunate combination of a subtropical, humid climate, hilly topography and poor land management strategies of the past have resulted in severe erosion (Whitney, 1986). This soil erosion has deprived the slopes of topsoil and nutrients, as well as caused soil degradation in the low-lying fields covered by the sandy sediments. In order to ensure long-term stability in crop yields, means of erosion prevention and control must be established. Furthermore, the nutrient status of the soils must be determined before the amount of fertilizer required to improve soil fertility can be calculated.

A nutrient is defined as a chemical compound necessary for the growth and metabolism of an organism, in this case a plant (Mengel and Kirkby, 1979). The nutrients that are the most important to plants, in terms of the amounts needed, are carbon, hydrogen, oxygen, nitrogen, phosphorus, potassium, calcium, magnesium and sulphur. These are classified as the macronutrients. Carbon, hydrogen and oxygen are obtained mainly from the air and water, sources that do not impose any limiting conditions in moist climates. The remaining macronutrients are obtained from the soil (Buckman and Brady, 1969). Iron, copper, zinc, manganese, chlorine, molybdenum and boron are classified as micronutrients. These are only needed in trace amounts and are also obtained from the soil. The functions of the different nutrients are given in Table 1.1.

The weathered granitic terrain of South China has been subjected to several periods of deforestation, and many slopes are scarred with rills, gullies and mass wasting features (Luk et al., 1987). Soil erosion is a two-phase process consisting of the detachment of individual particles from the soil, mainly by rainsplash, and their transport by running water and wind (Kirby and Morgan, 1980). The three types of erosion are:

i) interrill erosion which is brought about by rainsplash and overland flow

ii) rill erosion which is brought about by channelized

Table 1.1 Essential mineral elements and their role in plants (Foth,1984).

Element	Role in Plants
	Macronutrients
Nitrogen (N)	Constituent of all proteins, chlorophyll, and in coenzymes, and nucleic acids.
Phosphorus (P)	Important in energy transfer as part of adenosine triphosphate. Constituent of many proteins, coenzymes, nucleic acids, and metabolic substrates.
Potassium (K)	Little if any role as constituent of plant compounds. Functions in regulatory mechanisms as photosynthesis, carbohydrate translocation, protein synthesis, etc.
Calcium (Ca)	Cell wall component. Plays role in the structure and permeability of membranes.
Magnesium (Mg)	Constituent of chlorophyll and enzyme activator.
Sulfur (S)	Important constituent of plant proteins.
	Micronutrients
Boron (B)	Somewhat uncertain, but believed important in sugar translocation and carbohydrate metabolism.
Iron (Fe)	Chlorophyll synthesis and in enzymes for electron transfer.
Manganese (Mn)	Controls several oxidation-reduction systems, formation of O_2 in photosynthesis.
Copper (Cu)	Catalyst for respiration, enzyme constituent.
Zinc (Zn)	In enzyme systems that regulate various metabolic activities.
Molybdenum (Mo)	In nitrogenase needed for nitrogen fixation.
Cobalt[a] (Co)	Essential for symbiotic nitrogen fixation by *Rhizobium*.
Chlorine (Cl)	Activates system for production of O_2 in photosynthesis.

flow and

iii) gully erosion which is caused by all the above as well as mass movements such as flows and slides.

The effects of deposition of silt and sand are felt downstream. The advantage of deposition is the importation of nutrients on to the floodplains and fields. The disadvantage is the silting up of rivers, a process that increases flood hazard and degrades water quality and covers fields with sand. A project on the soil erosion is currently being conducted in Deqing County, South China. The present study constitutes part of the research but will focus only on the nutrient aspect of the study.

1.2 Theory

The formation of soils begins with the physical, chemical and biological weathering of rock materials. Chemical weathering is rapid in a hot, wet climate, with the parent rock determining the nature, and the decomposition process, the amount of nutrients released. Soils derived from biotite granite, which comprises mainly of quartz (SiO_2), orthoclase ($KAlSi_3O_8$), plagioclase ($NaAlSi_3O_8$) and biotite ($K_2Al_2Si_6(Fe^{2+},Mg)_6O_{20}(OH)_4$), are rich in potassium, magnesium, iron and aluminum, but poor in phosphate and calcium. The iron and aluminum form oxides to give the soils their florid colouring and also their group name of oxisols. The abundance of these oxides coupled with a paucity of base cations that have been replaced by H^+ (hydronium ions) results in the high acidity of the soils (Foth,1984):

$$M^{3+} + 3H_2O = M(OH)_3 + 3H^+ \qquad (1)$$

Where M represents aluminum and iron. Particle size also affects the availability of some nutrients. For instance, kaolinite, a clay, is one of the end products of weathered granite. Iron and phophorus tend to adsorb on to clay particles in their ionic or complex forms (Barber,1984).

The relationship between soil nutrients and plants can be expressed as:

$$\text{nutrient(solid)} \underset{k_1}{\rightleftharpoons} \text{nutrient(soil sol'n)} \underset{k_2}{\rightleftharpoons} \text{plant}$$

where the k's are the rate constants. The nutrient levels that are present in the soil at any time are the differences between the amounts added to and removed from the soil (Fig.1.1). In natural watersheds, the sources include the release of nutrients through weathering, bacterial fixation and those inputs accompanying rainfall and dry deposition (Proctor,1987). The last two inputs should be small unless there is a source of atmospheric contaminants nearby, such as a factory. In agricultural regions, a major input could be fertilizer.

As plants colonize a soil, the plants, soil and microorganisms develop an equilibrium relationship whereby inputs into the system are eventually absorbed by the plants from the soil solution. When a plant or a part of it dies it is returned to the soil as litter and decomposes to

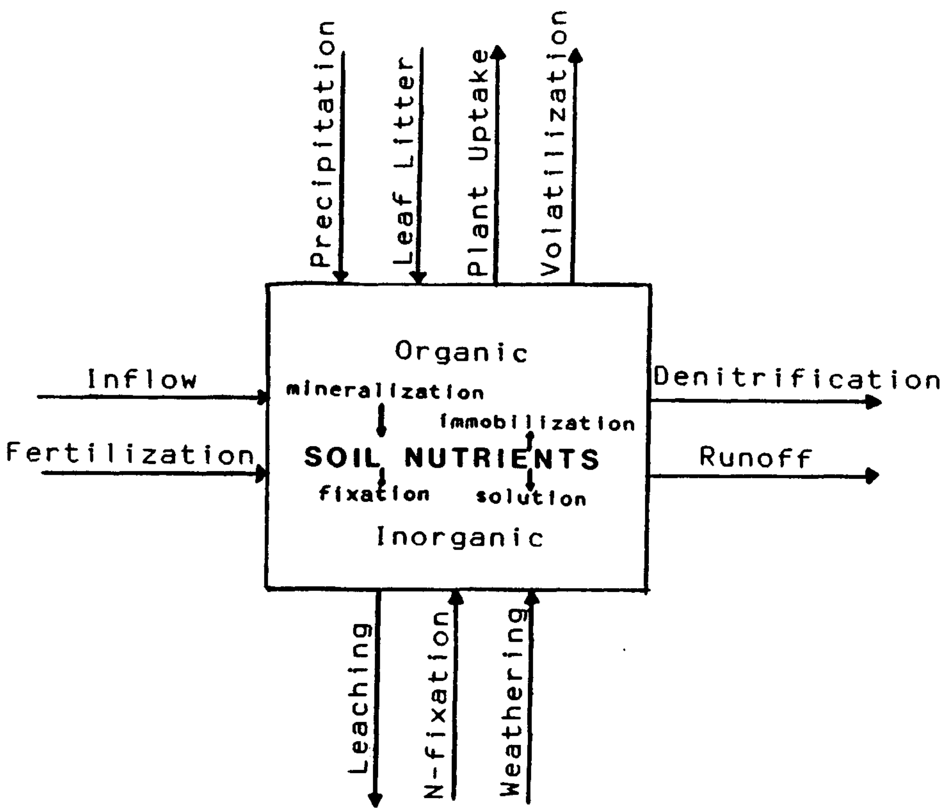

Fig.1.1 Nutrient inputs into and outputs from soil. Some nutrient cycling takes place within the soil matrix itself.

form organic matter, thus returning the nutrient to the soil (Wells,1977). Moreover, roots retrieve some of the nutrients leached into the soils and most nutrients integrated into plant matter are protected from leaching losses (FAO, 1979). It had been thought that, despite very high rates of vegetation production, destruction by bacteria is often too rapid for humus formation, so that tropical soils remained poorly developed (National Academy of Science, 1972). However, undisturbed rainforests are productive and stable ecosystems even where soils are poor. Recent observations suggest that this is possible because nutrients are recycled between living and dead organic matter without contact with the mineral soil (FAO, 1986; Charleton, 1987). Furthermore, rapid recycling reduces loss by leaching (FAO, 1984). Soil nutrients are the nutrient capital which can be lost from the system (Likens, 1985).

Nutrients can be lost through leaching, surface erosion, fires, volatilization and denitrification (Proctor,1987). In undisturbed watersheds underlain by an impermeable substrate (such as granite), loss is mainly through erosion (Likens and Bormann, 1972). In agricultural fields, the equilibrium of the nutrient cycle between vegetation and soil is interrupted by the removal of large portions of the plant biomass (FAO,1984). These losses lower the potential productivity of the soil and must then be compensated for by the addition of fertilizer

(FAO,1979; Tivy,1987).

Nitrogen exists in organic and inorganic forms; the latter is directly utilized by plants. Inorganic nitrogen consists of nitrate, nitrite and ammonium (Mengel and Kirkby,1979). Nitrite is rarely found under natural conditions as it is very labile and is quickly oxidized into nitrate under well-drained conditions. Usually, inorganic nitrogen is derived from the decomposition of organic matter by bacteria. In highly acidic soils bacterial action is inhibited and the nitrification is arrested at the ammonium stage (Poovarodam et al.,1988).

Unlike nitrate and ammonium which are reasonably stable in their free forms, orthophosphate is highly reactive. In granitic areas where phosphorus is limited, it tends to complex with iron and aluminum and becomes unavailable to plants (Tivy,1987). In time these complexes are adsorbed onto soil particles which transforms them into less soluble forms (Foth,1984). Ionic aluminum and iron can also reach toxic levels in the soils, suppressing root growth. This is particularly problematic for the lower soil layers which cannot be reached by liming (Bates et al, 1985).

Soils derived from granite are poor in calcium because the parent rock is deficient in calcium. Calcium is an important nutrient and dicotyledonous plants such as legumes require more calcium than monocotyledons such as grasses (Chapman,1966). Peanut plants subject to calcium stress will abort their kernels (FAO,1984). Furthermore, the nitrogen fixing capacity of legumes is inhibited when soil pH falls below 5 due to poor nodule development on the roots (FAO, 1986, OMAF,1988). This can cause a conflict in crop management practices since the growth of legumes is a cheap way of adding nitrogen to the soil but at the same time requiring expensive additions of lime.

Potassium and magnesium ions are very mobile and are easily leached from soils. However, potassium is more strongly held to soils (FAO,1970). Plants also take up more potassium (Lowrance, 1984). It is, therefore, frequently stored in the plant whereas magnesium is leached out of the soils. During a rainstorm, some potassium is washed off the plants because it does not form an integrated unit in the plant matter matrix (Foth,1984; Puckett,1987).

1.3 Nutrient Transport and Land Reclamation for Agriculture

The nutrient cycle is tied into the hydrologic cycle (Jones, Borofka and Bachmann,1976; Webb and Walling,1985). Most of the nutrients are lost during periods of high flow (Hill,1978) when erosion is intense, but the amounts of water, sediment and nutrient loss are related not only to precipitation but also to land use (Beaulac and Reckhow,1982; Feller and Kimmins,1985; Prairie and Kalff, 1985).

Soil removal occurs through entrainment and transport (Morgan,1979). Severe erosion will remove topsoil from upland slopes that have been stripped of vegetation (Buckmann and Brady,1968; FAO,1979; Kirby and Morgan,1980). Vegetation protects the soil surface from rainsplash, the roots anchor the soil and improve infiltration, promoting better structure and more stable aggregates which results in less erosion. Still, even on densely vegetated areas, erosion, though slight, may cause a loss of nutrients. Hence, a bare slope will yield a high discharge but a low nutrient concentration, whereas a vegetated slope should yield a low disharge but a high nutrient concentration because vegetation contributes nutrients but reduces surface runoff.

Ammonium, nitrate and potassium are highly soluble and will be lost mainly through runoff, but could also be lost by leaching, enriching groundwaters. Calcium and Magnesium are mainly leached off acid soils. Phosphorus and iron, which tend to adsorb on to particles, will be largely lost with the sediments eroded from the slopes (Sharpley, 1980; Ahuja et al., 1982; Sharpley et al., 1982). Nutrient transport through runoff and sediment is an important part of the nutrient cycle in the basin.

Gully formation is favoured where runoff is concentrated by the topography (FAO,1979). Slumping of unstable gully headwalls and transport of sediments by running water very quickly gives rise to colluvial fans in the valleys (FAO,1986). Finer particles are carried further away from the source before deposition. They form relatively impermeable layers that retard infiltration and, in time, a wetland can be formed. The colluvium and the fines may be reworked by streams to form alluvial floodplains. These floodplains may be utilized later for cultivation.

Most field crops grow best on soils with a pH level between 5.0-8.0 (OMAF,1988). Soils in the humid tropics are often highly acidic and not very fertile (Landon,1984). In general, cropping breaks down soil structure and depletes the soil of nutrients by interrupting the nutrient cycle (FAO,1970). The larger the crop yields, the more nutrients removed (FAO,1980a). Nutrient requirements vary for different plants from region to region. Low soil nutrient levels will be reflected in poor crop yields (Mengel and Kirkby,1979). At the simplest level, a soil test will determine whether fertilization is required. The choice and amount of fertilizer will depend on the type of deficiency, the suitability for the area and the costs involved. In developing countries such as China, mainly organic fertilizers are used (FAO,1978). It is therefore necessary to determine the nutrient levels of the cultivated soil to establish the deficit and, hence, the level of fertilization required.

1.4 Research Objective

The objective of this study is to evaluate the nutrient status of the soils of Shenchong Basin and how it is affected by soil erosion.

More specifically, the study will concentrate on:

i) evaluating nutrient levels in the upland and lowland soils

ii) determining the effects of vegetation on soil nutrient levels as well as

iii) analyzing losses of nutrients from the slopes in surface runoff and the role played by vegetation in ameliorating these losses

iv) analyzing nutrient levels in the organic fertilizers

v) looking at the implications of the above on agriculture in the basin and making future recommendations.

The Shenchong basin is typical of the granitic areas in Guangdong Province where serious soil erosion occurs. Results of the study can be extrapolated to other regions of South China where the physical and the human environments are similar.

CHAPTER 2

FIELD AREA AND METHODOLOGY

This chapter describes the location and physical setting of the field site and the field and laboratory methodology involved in obtaining and analyzing the samples.

2.1 Field Area

2.1.1 Location and setting

Deqing County is located in Guangdong Province in China at 23^0 10'N 111^0 50'E. It is situated in the middle reaches of the Xijiang (West River) 240 km northwest of Guangzhou (Fig.2.1). Soil erosion continues to be a major problem in the county. Serious erosion began in the 16th century when large tracts of forest were felled so that rebelling peasants could not hide in them (Deng,1986). This was followed by centuries of deforestation to obtain fuel. Deposition of eroded material on the lowland areas buried fields and destroyed agriculture in the region. During the 1850's the situation became so critical that half the population in the county, estimated at 330,000, had to be resettled (Luk and Yao,1987). Even today the population (176,000) has not attained its previous levels. With the advent of the Communist Government ambitious reforestation

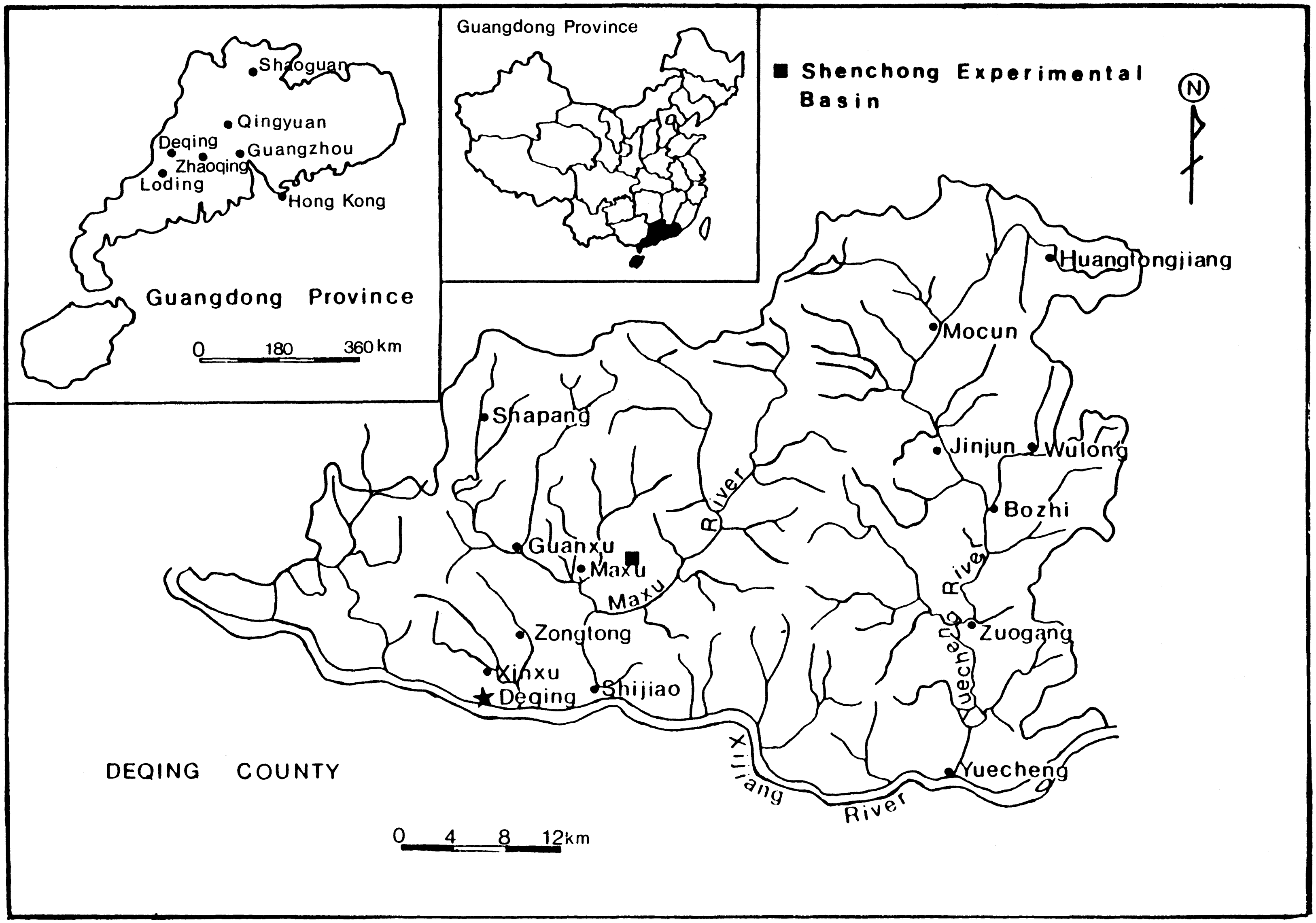

Fig.2.1 Location of Deqing County in Guangdong Province.

schemes were undertaken but were never brought to complete fruition because of the Cultural Revolution. During this period shortages of fuel again drove the local populace to cut the trees on the slopes.

Today reforestation and land reclamation are, once again, priorities. A joint Chinese-Canadian project was initiated in 1986 to investigate avenues for dealing with the implementation of these priorities. Fieldwork for this study was carried out from May through to August 1987 in Shenchong Basin in western Deqing. This location was chosen because it was considered representative of the landscape which was of interest.

2.1.2 Topography

The hilly terrain of Shenchong Basin is broken up by gaping gullies known locally as 'tiger' gullies (Fig.2.2a) and deeply incised rills on the steep, bare slopes. The basin covers an area of 0.9 km^2 with elevations between 46.0 and 160.0 m above sea level (Fig.2.3) The valleys are wide and shallow with an average gradient of 1 in 600 (Luk et al,1987). The valley floors are covered with colluvial deposits which in some cases have been reworked by the creek into alluvium (Fig.2.2b). Some conservation practices such as check dams have been established in recent years. Even so, 11.6% of the upland areas and 75% of the low-lying areas are affected by

Fig.2.2a An example of a 'tiger' gully in Shenchong Basin.

Fig.2.2b Valley floor of Shenchong Basin which is covered with alluvial and colluvial deposits.

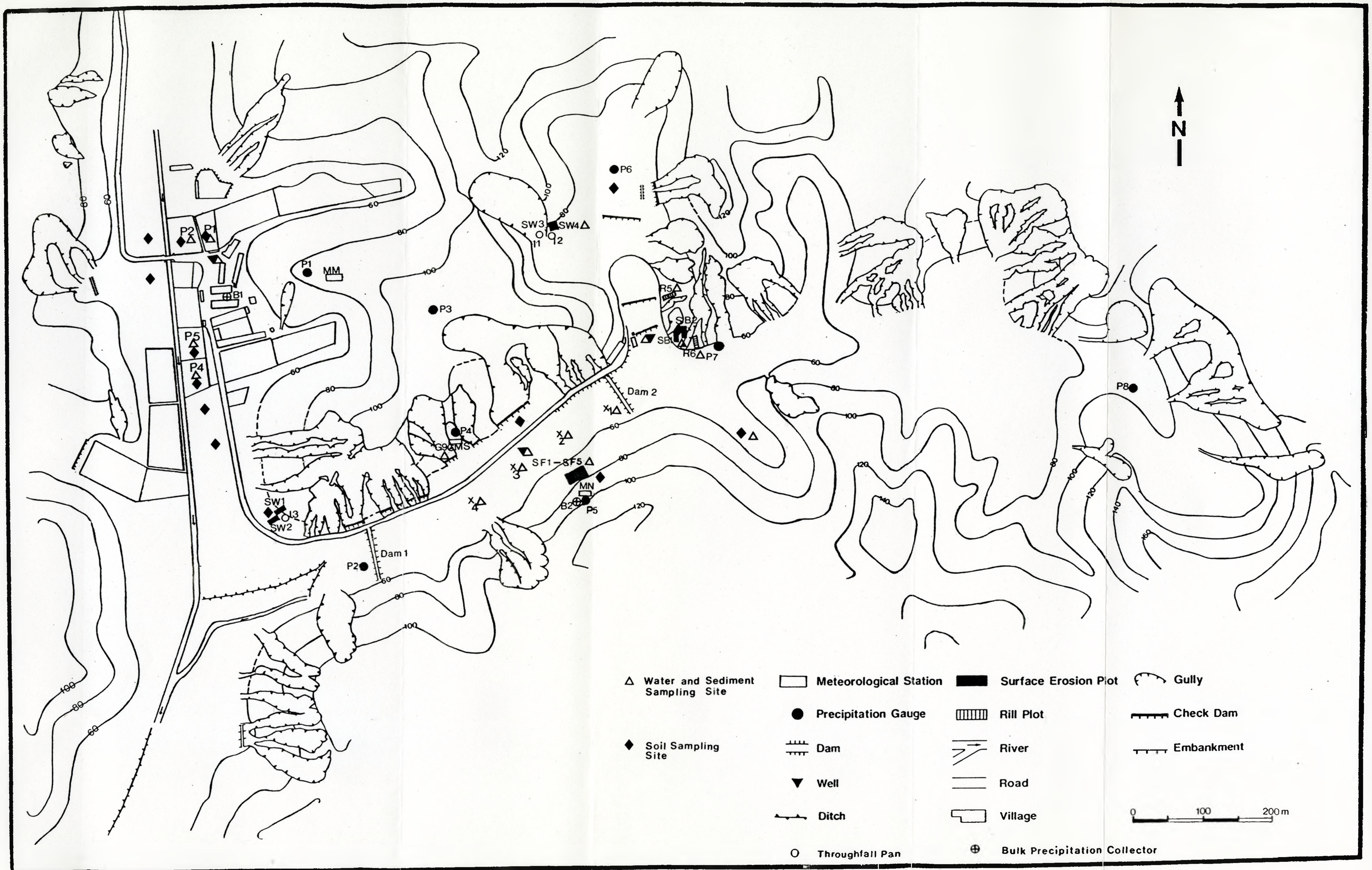

Fig.2.3 Topographic map of Shenchong Basin with the locations of field equipment and sampling sites shown.

erosion causing severe problems for the farming community (Whitney,1986).

2.1.3 Geology

Topography in Deqing is differentiated by the underlying geology. Higher elevations are underlain by sandstone, shale and limestone and are subject to sheet erosion. The low hills between the elevations of 36 and 96m are associated with granite intruded during the Yenshan Orogeny of the Cretaceous Period (Luk,et al.,1987). It is amid these hills that erosion is at its most severe.

The dominant rock type is biotite granite consisting of 34.8% orthoclase, 26.3% plagioclase, 33% quartz and 5% biotite. The high density of joints must have facilitated weathering. The depth of the weathering mantle is 32m on average, and comprises the following vertical zones:

surface -- the top 1-3 m consists of a clayey sand soil with a granular structure, brownish red in colour and with very little organic matter

zone 1 -- approximately 13 m in depth, massive structure, high $Al^2{}_{O3}$ and Fe_2O_3, intense kaolinization

zone 2 -- 12 m depth, moderately weathered, lower Fe_2O_3 than the zone above, a crystalline structure of minerals still discernible

zone 3 -- 4.73 m, weakly weathered, crystalline structure readily discernible, yellowish stain and most of the feldspars have been converted to kaolinite

zone 4 -- slightly weathered

zone 5 -- bedrock

2.1.4 Soils

The soils on the hillslopes exhibit a bimodal particle size distribution consisting of coarse sand and clay. Silica and sand content increase with depth while Al_2O_3, Fe_2O_3 and clay decrease with depth. The soils have low cohesion and are acidic (Luk et al.,1987). The latter can be attributed to the high aluminum levels which make Al^{3+} the dominant exchangeable cation. The soils are classified as oxisols.

Deposits of sand and silt from the slopes form colluvial and alluvial fans on the lowlands. At the distal ends of the fans, the finer deposits accumulate into relatively impervious layers that eventually maintain wetland conditions.

2.1.5 Climate

The Tropic of Cancer passes close by Deqing. Hence, Deqing recieves high solar radiation, approximately 4,395 MJ/yr. The mean annual temperature is 21.5^0C and the annual maximum reaches 37.5^0C with an annual minimum of 6.2^0C. The climate is subtropical, being characterized by long, hot summers and short, cool winters.

Although 200 km inland from the coast, Deqing is influenced by maritime air masses. In winter the northern air mass dominates resulting in low temperatures, dry air and sunny days. In spring the cold air mass is weakened by the time it reaches Deqing. When it meets the warm, moist maritime air mass the Nanking Stationary Front is formed and heavy precipitation results. This first rainy season ends when the ridge moves northwards and is then followed by the 'typhoon' season. During this period the southeast monsoon brings heavy rains from the South China Sea. The entire rainy season lasts from April to September and 77% of the total annual rainfall for this region falls during this period. Total annual precipitation, based on the record from 1966-1986, is 1517 mm with an average of 111 rain days (Luk et al.,1987).

2.1.6 Vegetation

The monsoon climate of South China gives rise to wet and dry seasons. The natural vegetation consists of deciduous trees and shrubs. The trees adapt to the moisture deficiency during the dry season by shedding their leaves. The tree canopy is less dense than that of a true rainforest, allowing more sunlight to reach the forest floor resulting in a greater variety of plant species. This is known as a semi-evergreen rainforest (Walter,1979).

The natural vegetation in Shenchong basin at present consists of secondary growth communities that have replaced the climax vegetation of the past which was destroyed by logging and forest fires (Fig.2.4). A single

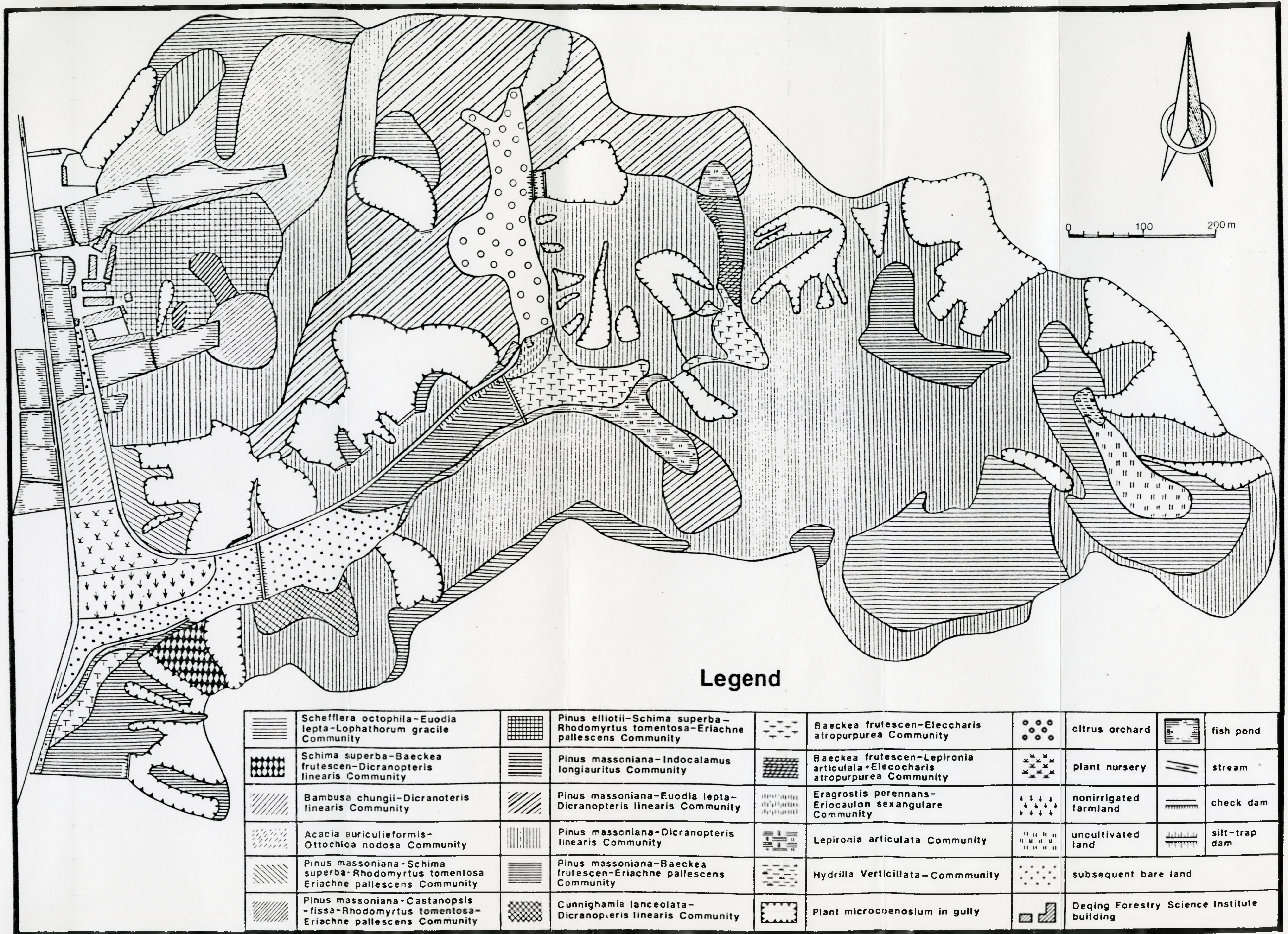

Fig.2.4 Location of vegetation communities in Shenchong Basin (Luk et al.,1987).

Caryota Ochlandra was found in the northeast corner of the basin and is thought to be the surviving member of the former climax vegetation of a monsoon broadleaf evergreen forest (Luk et al.,1987).

When the forests existed the high density canopy and multistorey structure provided adequate protection from raindrop splash and subsequent detachment of soil particles by overland flow. In comparison, the present plant communities are vastly inferior in this capacity. Species such as the **Pinus Massoniana** do not have the multistorey structure so important for interception and the sparse grasses on the floor do not provide a complete cover.

The species of plants that grow on the slope reflect the degree of moisture and shade available. Bracken fern has colonized the north-facing slopes as well as the shaded slopes where deep gullies have developed. The fern possess strong binding roots which greatly reduce soil erosion. Unfortunately, its usefulness as a fuel makes it subject to removal by the populace.

2.1.7 Agriculture

The wetlands have been dredged to become fishponds in which carp, prawns and snails are kept for sale in the local market. The fans and floodplains have been reclaimed for the cultivation of peanuts, citrus fruits, bananas, cassava, beans, cucumber and medicinal herbs (Fig.2.5a).

Fig.2.5a Citrus field in tributary valley.

Fig.2.5b Surface plots SB1 and SB2 are located on a 'bare' slope. The vegetation there consist of isolated pine stands and coarse grass.

The peanuts and cassava are planted in rotation to take advantage of the nitrogen fixing properties of the peanuts. The predominantly sandy soil, however, is not a good medium for cultivation as it possesses little organic matter and its high porosity allows nutrients to be easily leached from it. To remedy this, topsoil from the fern slopes is excavated to cover the fields. This encourages erosion on the slopes.

To improve the nutrient content in the agricultural soil, both organic and inorganic fertililizers have been added. Most of the fertilizers are organic. The source materials include pondmud, burnt grasses and refuse from abatoirs. The pondmud is taken from the floor of the ponds which are drained twice a year. Slurries from the pig styes and outhouses are regularly emptied into the ponds to enrich the mud with nutrients. Grasses and weeds are burnt to release the nutrients, and then ploughed back into the soil. This is the most common form of fertilizer as it can be obtained whenever the grass is overgrown and it does not cost anything. The major drawback is the susceptibility to leaching and loss through volatilization associated with the burning. Refuse from the abatoir consists of meat scraps, blood and hair. Like inorganic fertilizer, this is not commonly used as it has to be purchased from an outside source.

2.2 Field Methodology

Since the study was part of a larger project, it was possible to deploy and monitor a considerable amount of equipment over the study area (Fig.2.3).

2.2.1 Meteorological Data

Three meteorological stations and a rain gauge network were established in late May, 1987. A main station was located near the top of a hill overlooking the field plots and two stations were set up, one on a north-facing slope and the other on the south-facing slope to observe aspect related differences. At the main station data were recorded by means of a programmable data logger (Campbell Scientific, Model CR21X). Data were sampled at 10 minute intervals and then averaged or totalled hourly.

Air temperature was measured at the main station at 2 m above the ground with a Campbell Scientific probe (Model 207) precise to $0.1^{0}C$. Chinese thermographs precise to $0.5^{0}C$ were used to measure temperature at the north and south slope stations. Temperatures were also checked by mercury thermometers. Data were recorded from July 13 to September 15.

The rain gauge network consisted of 8 gauges (P1 to P8). P1 was a tipping-bucket gauge hooked up to the CR21X data logger. Each tip was calibrated to represent 0.1 mm of rainfall. P2 to P8 were 'weigh-type' gauges with rainfall recorded on a chart and coded for 10-minute intervals. Meteorological Service of Canada standard rain gauges were placed alongside the recording gauges to serve as a check. Data were obtained from June 1 to August 17.

2.2.2 Surface flow data

Fifteen enclosed study plots, ranging in size from 1x10 m^2 to 2x10 m^2, were set up to monitor the rate of soil erosion on selected slopes with different types of vegetation. These plots were situated on the bare (SB1 and SB2), forested (SW3 and SW4), revegetated (SW1 and SW2) and fern (SF1 to SF5) slopes. Later on, sampling at the revegetated plots had to be abandoned because of shortage of labour.

Plots SB1 and SB2 were located on a bare slope scattered with isolated stands of pine trees (Pinus Massoniana) and coarse grass (Fig.2.5b). On July 5, what pine needles there were on SB1 were cleared and more pine needles scattered on SB2 to make up a covering of approximately 100% and 1 mm in depth. These plots were occasionally checked to verify coverage. The slope angle for SB1 and SB2 are 20.2^0 and 30.9^0 respectively. The slope aspect for SB1 and SB2 were 180^0 and 170^0 (south-facing) respectively.

Plots SW3 and SW4 were located in a natural forested area (Fig.2.5c). The slope angles for SW3 and SW4 are 34.5^0 and 37.2^0 respectively. The slope aspect was

Fig.2.5c Surface plots SW3 and SW4 are located on a forested slope.

Fig.2.5d Surface plots SF1-SF5 are located on a fern covered slope.

about 120^0 (east-facing) for both the plots.

Five of the fern-covered plots were monitored to study the effects of various percentages of vegetation cover on soil erosion (Fig.2.5d). On June 16, a grid was placed over each plot and each grid cell randomly stripped to obtain the desired amount of cover. The plots were stripped to leave 0% cover (SF4), 25% cover (SF3), 50% cover (SF1), 75% cover (SF5) and 100% cover (SF2). The slope angle of the plots is about 27.0^0 and the slope aspect is approximately 323^0 (north-facing).

The impermeable boundaries for each plot were made of brick and mortar and were 15 cm in height and 6 cm in width. The enclosure was both to prevent upslope water from flowing into the plots and leakage from the plots. The downslope side of each plot was shaped into a shallow "v" to direct the runoff towards a PVC pipe cemented into the terminus of the v-shaped front. The pipe was silicon sealed to a plastic funnel which itself was attached to a length of plastic hose to empty into a 50-litre plastic bin. The bins were each placed on previously levelled surfaces and were kept in place by bricks cemented into position. During very hot weather (above 40^0C) the silicon seal melted from the funnels and the funnels fell off. These then had to be reattached using duct tape and electrical tape. After the storm of August 11, bamboo cross pieces were put beneath the funnels for support. Measurements of depth in the bins were converted into volume by using a formula that treated the bin as a truncated cone:

$$V = [\pi(1.8995 + 0.069x)^2(h + x)/3] - 101.765 \quad \text{.....(Eq.2-1)}$$

where h is 273.4 cm and x is the depth of water in the bin measured with a tape measure (Woo and Young, 1987).

2.2.3 Rill runoff data

Two rills were monitored, one of which (R5) was bare while the floor of the other (R6) was covered with bracken fern. These plots included the entire drainage areas of the rills. Only the v-shaped frontispieces were constructed at the lower end of these rills to collect runoff. A similar pipe-funnel-hose setup to that used at the surface erosion plots was applied to the central terminus of rill plots. The data collection routines for these plots were similar to those for the surface erosion plots.

2.. Gully runoff data

Gully G9C on the south-facing slope was selected to represent the many gullies in the basin. The gully drains an area of 3,400 m^2. At the outlet of this gully, a 90^0 v-notch was cut into a steel plate to form a weir behind which was set a water-level recorder to provide stage measurements.

2.2.5 Water and sediment samples

Runoff responded very quickly to the most intense parts of the storms. Thus, to obtain detailed information during a storm, water and sediment were sampled once every 5-10 minutes. To obtain a sample a 1-litre polyethylene bottle was placed at the mouth of the hose leading to the collecting bin and the lapsed time required to fill the bottle noted. Each bottle was washed and rinsed in deionised water prior to being brought to the field. Early in the season, preparation of the bottles had included soaking in 0.1 M HCL but the difficulty of obtaining fresh supplies of acid precluded continuation of this procedure. When the collecting bins had filled up, the contents were mixed up and the depth recorded and a sample taken for totalised sediment results. Water and sediment were sampled every 2-5 minutes at gully G9C by placing a series of 1-litre bottles below the v-notch.

2.2.6 Rainwater samples

In order to assess the nutrient contribution from rainwater, and interception of the raindrops by plants in the subsequent throughfall, samples of rainwater were collected. Rainwater was collected in 1-litre polyethelene bottles topped by plastic funnels. These were placed close to the recording gauges to obtain rainfall data to correspond to the bulk analysis.

The influence of interception and throughfall was determined from water samples collected in wide shallow plastic pans measuring .05 m^2 covered with a plastic mesh to keep out insects and leaves. These 'interception pans' were placed under different kinds of vegetation. The necessity of carrying out the tests within 24 hours, to prevent contamination from bacterial activity, meant that in the case of very dense vegetation such as at P3, the intercepted rainfall did not have sufficient time to drip onto the pan.

2.2.7 Soil samples

Samples of soils taken from a bare, a forested, a fern-covered and a revegetated slope were used to represent upland soils. Agricultural soils from peanut, citrus, baji, banana and cassava fields were also sampled. In addition, sediment samples from the colluvial fans, alluvial floodplains and mud samples from the fishponds and the wetland were collected and used to represent the unimproved lowland environment. Soil samples were collected three times during the field season; May 22-29, July 16-20 and August 13-18.

When sampling soils from a field, the first pit was located randomly. An additional pit was dug some 10 m from it. If a third pit was dug, it formed a triangle with the other pits. When sampling a slope, the first pit was located 3/4 of the way upslope, then 1/2 way and finally 1/4 way upslope. Each pit measured .5x.5x.5 m^3 (although in some cases the pits were deeper). Soil was then collected at equally spaced intervals in each horizon and placed in polythene bags. Soils were tested for texture and structure using the Field Guide to Forest Ecosystem Classification (Jones et al.,1983). A total of 59 pits were dug and 177 samples obtained over the summer. When brought back to the field station, these samples were immediately broken up and air-dried to prevent any further bacterial action.

A portion of each of the soil sample was tested for pH using a method described by Langdon (1984). Water was added to the soil at a soil to water ratio of 1:5. The mixture was stirred to form a slurry and then it was allowed to stand for 15 minutes before the electrodes were immersed to obtain a pH reading.

2.2.8 Chemical analysis -- field and pH data

Many pieces of equipment as well as chemicals shipped from Canada to China were delayed by Chinese Customs and it was not until mid-June that the shipment arrived. On June 17, pH measurements were taken for water samples collected from different locations around the basin using a Cole-Palmer digital pH meter. Measurements were taken on a weekly basis until the equipment malfunctioned due to both high humidity and temperature. Before being taken out to the field the pH meter was regularly calibrated using buffer solutions of pH 4.00, 7.00 and 10.00. Samples from the same locations were also brought back to the field laboratory to test for nutrients in the water.

2.3. Laboratory Methods

2.3.1 Sample preparation -- water/sediment samples

The field samples were brought back to the laboratory in 1-liter bottles. Each sample volume was determined using a 1-litre graduated cylinder. The contents were then transferred into beakers to allow the sediment to settle. This strategy proved ineffecient and was replaced by the following procedure. The volume of each sample bottle was determined and marked on it. During a storm each sample bottle was filled to the brim and closed. On arrival at the laboratory, the date, time, location and volume were recorded. The bottles were then shaken to obtain a homogeneous mixture and a 250 ml. aliqout was taken for nutrient testing. This was filtered using a vacuum pump and 40 um Whatman filter paper. The filter papers had been previously weighed to ± 0.1 mg using an analytical balance.

The remainder of the sample was allowed to sit until most of the sediment had settled. The liquid portion was then decanted and filtered to remove the fine sediment in suspension. In the case of very fine particles which could not be separated by filtering, a drop of concentrated (6.0 N) nitric acid was added.

The addition of the acid served to collapse the attraction between the water molecules and the fine particles which was keeping the latter in suspension. The acid was non-contaminating as only a small quantity was introduced and what was present would have volatilized when the sediment was dried.

2.3.2 Spectrophotometric analysis of water samples

Danger of contamination from bacterial activity made it essential for the tests for ammonium, nitrate and orthophosphate concentration in the samples to be carried out within the same day. Tests were carried out on a Coleman II spectrophotometer and a Cole-Porter colorimeter. Both pieces of equipment had been calibrated before shipment to China; but the high humidity and unreliable electric power supply caused problems with the equipment, especially the Coleman II spectrophotometer.

Spectrophotometry works on the principle of concentration being linearly related to the attenuation of a light beam passing through the treated sample, according to the Beer-Lambert Law. The spectrophotometer was zeroed using a blank consisting of the untreated sample. The sample was pre-treated with a reagent to produce a colour. An aliquot of the sample was placed in the sample chamber of the spectrophotometer and the wavelength dial adjusted for maximum sensitivity. The degree of light transmission was registered on a scale. Colorimetry works on a similar principle except that instead of adjusting the slit-size and wavelength, different coloured glass filters are used for the same purpose (McAllister,1981).

The test for ammonia was the standard Nessler reagent test. 1 ml of Nessler reagent was added to 25.0 ml of the sample. If ammonia was present a yellow colour would develop, and after waiting 10 minutes for full colour development, the sample aliquot was analyzed on the spectrophotometer set at a wavelength of 425 nm or using a blue filter.

When testing for the presence of nitrate, cadmium filings were used to reduce the nitrate to nitrite. The sample was then treated to produce a pink colour. Again, 10 minutes were allowed for complete colour development before analysing the aliquot on the spectrophotometer set at a wavelength of 500 nm or using a green filter.

The test for the presence of orthophosphate involved treating the sample with ascorbic acid to obtain a blue colour. Two minutes were allowed for full colour development. The aliquot was then analyzed on the spectrophotometer set at a wavelength of 700 nm or using a red filter.

All the tests were carried out using reagents

obtained from Hach Chemicals. With the exception of the Nessler reagent the rest of the reagents were in solid form and were shipped in small packages containing enough reagent for each test thus dispensing with the inconvenience of having to measure out precise amounts on the field. A volume of 30 ml. of each sample was set aside and refrigerated for shipment to Guangzhou where they were analyz
ed for potassium, iron and calcium at the Guangzhou Institute of Geography.

2.3.3 Analysis of soil samples

A limited number of soil samples were brought back to Canada for analysis. Unfortunately, only very small samples (< 10 g) were allowed out of the country, and this amount was insufficient to be divided for different tests. To overcome the difficulties of small sample size, the samples from the same field or slope were combined. These were tested at the Land Resources Laboratory at Guelph University for nitrate, available phosphorus, exchangeable iron, potassium, calcium and magnesium.

To test for available nitrogen,the soils were shaken in a solution of 2N potassium chloride for 15 minutes and filtered using 42 um Whatman filter paper. The nitrate in the filtrate was then reduced to nitrite using cadmium and then spectrophotometrically analyzed on an auto-analyser.

To test for available phosphorus, the soils were treated with 0.5 M sodium bicarbonate and shaken for 30 minutes after which the mixture was filtered. The filtrate was then treated with molybdate reagent and then spectrophotometrically analyzed.

Exchangeable iron was extracted using a solution of IN sodium pyrophosphate and the filtrate was then analyzed on a Varian Atomic Absorption unit. Extractable potassium, calcium and magnesium were all extracted using neutronormal sodium acetate. The calcium and magnesium were analyzed using the technique of atomic absorption, while the potassium test utilized flame photometry.

Levels of total aluminum were determined using instrumental neutron activation analysis (INAA). Aluminum is not a nutrient but it plays an important role in soil toxicity and acidity. INAA requires a very small amount of sample and for certain elements is extremely sensitive even at trace concentrations. The method is non-destructive; and it avoids the possibilities for contamination inherent in pre and post radiation chemistry. INAA also provides multi-elemental analysis but the major disadvantage in this case was the extremely high background noise levels due to the very high aluminum levels in the soil matrix. Hence, the levels of total magnesium and potassium determined by INAA were deemed unreliable because of the large analytical error associated with them.

2.3.4 Procedure for INAA

A soil sample of 0.2 g, placed in a polyethelene vial, was sent to the reactor core in a 'rabbit' via a vacuum chamber. In the core the sample was exposed to a low intensity neutron flux for 20 seconds. The 20 seconds was a compromise so that exposure was long enough to activate the nuclides of the elements but short enough that the sample cooling time would not slow down the process. The vial was then sent back to the laboratory where it was allowed to cool for 20 minutes and then removed from the rabbit. Twenty minutes was considered the shortest time possible before the sample was cool enough for the detectors to function efficiently. Afterwards, the vial was placed before an APTEC germanium crystal detector to count the gamma rays emitted from the sample as the radioactive isotopes decay. Each sample was counted for 10 minutes. Due to the large number of samples and the long delay time, after the first 20 samples the ORTEC detector was used concurrently with the APTEC detector so that two samples could be counted simultaneously. The detectors themselves were coupled to a multichannel analyser (Canberra Series 90) which amplified, sorted and displayed the emission counts as a series of peaks each representing an element according to its half life.

Standards of lake sediment, marine sediment, coal and 99% pure aluminum oxide of known concentrations, with similar weights to the soil samples were analyzed using the same irradiation, delay and count times as the samples. The results were stored as a data library. When calculating the elemental concentrations the data library was accessed through the PEAKF execution programme and the input data compared to the library to determine the concentrations. Inputs for this programme were peak energy and background energy levels, a flux correction factor, exact weight of the sample, irradiation, delay and count times.

The relationship exploited is

$$PPM_{sam} = PPM_{std} \left[\frac{W_{std}}{W_{sam}}\right] \left[\frac{N_{sam}}{N_{std}}\right] e^{-\lambda(td_{std} - td_{sam})}$$

where: W = weight of sample
N = weight of element x isotopic abundance x 6.023 $\times 10^{23}$ x atomic weight
λ = decay constant related to half-life
td = delay time after removal from reactor core
sam = sample of unknown concentration
std = standard of known concentration

The analytical error is derived from the background counts. Generally, the weaker the peak with respect to the background the larger the error (Gladney,1981). This did not prove to be a problem in the case of aluminum because the aluminum peak was very pronounced.

CHAPTER 3

THE UPLAND ENVIRONMENT

This chapter deals firstly, with the upland soils that are the source of sediment and nutrients and, secondly, with the processes that transport the water, sediment and nutrients out of the uplands.

3.1 Soils in the Uplands

The upland areas of Shenchong Basin can be divided into three land use categories according to the intensity of erosion: areas of very high erosion with slopes subject to disintegration, areas of severe sheet erosion and areas of slight erosion. The first category includes gullies and rills, the second category refers to the bare and revegetated slopes, and the last category covers the vegetated slopes such as those with fern and forest covers.

3.1.1 Soils in areas of high erosion subject to disintegration

Soils in this area are described by Luk et al. (1987). These soils have been severely eroded and generally the A horizon is absent, though sometimes a thin AB horizon may exist. The B_1 horizon is about 35 cm deep with a dry soil colour of 10R 6/8. The soil texture is clayey with a significant stone content and the soil structure is blocky with no roots present. The B2 horizon is 117 cm deep with a dry soil colour of 10R 6/8. The soil has a texture of loamy clay with plentiful stones, a blocky structure and no roots present. The soil pH is about 4.74 and the chemical composition is given in Fig.3.2a,c,f and g and will be discussed later.

3.1.2 Soils from areas of heavy sheet erosion

Soil samples were taken from the slope where SB1 and SB2 are located as an example of a bare slope. The slope has been so heavily eroded that strictly speaking, it does not possess an A horizon. An AB horizon, about 15 cm thick consists of a loamy sand with a dry soil colour of 2.5YR 5/6. The B horizon, approximately 46 cm thick, is a silty gravel with chunks of granite embedded in it. The dry soil colour is 5YR 5/6. The soil pH is 4.16 and the nutrient composition is shown in Fig.3.1a (the relative error associated with these results is ± 5%).

Although the reforested slopes are vegetated, in some cases the sparse ground cover allows for quite significant sheet erosion. An example is furnished by the slope where SW1 and SW2 are located. The angle of the slope is approximately 19^0. The 10 cm thick O1 horizon is a loamy sand with a crumbly structure containing plentiful twigs, roots and leaves with a dry soil colour of 7.5YR 5/4. The

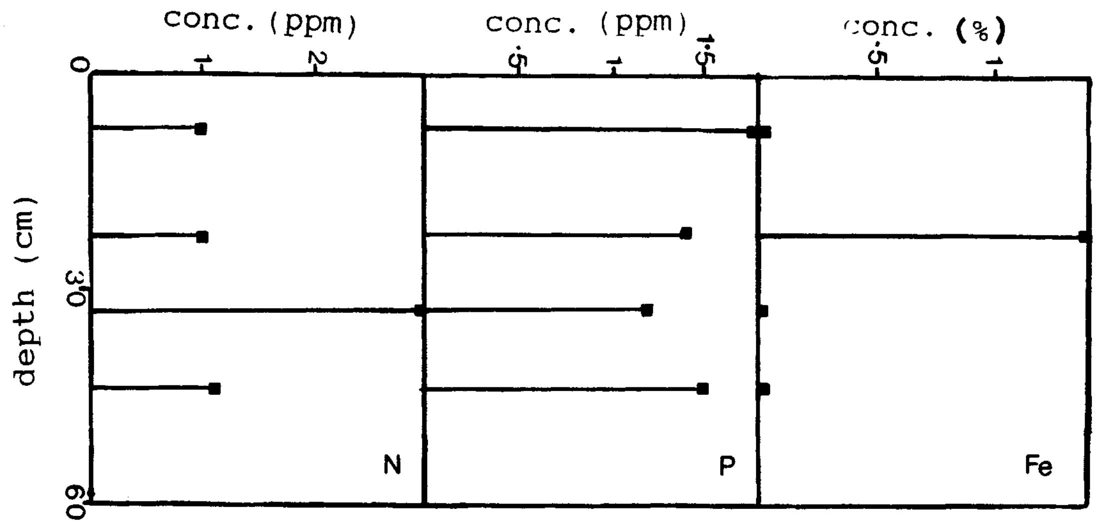

Fig. 3.1a. Concentrations with depth, bare slope

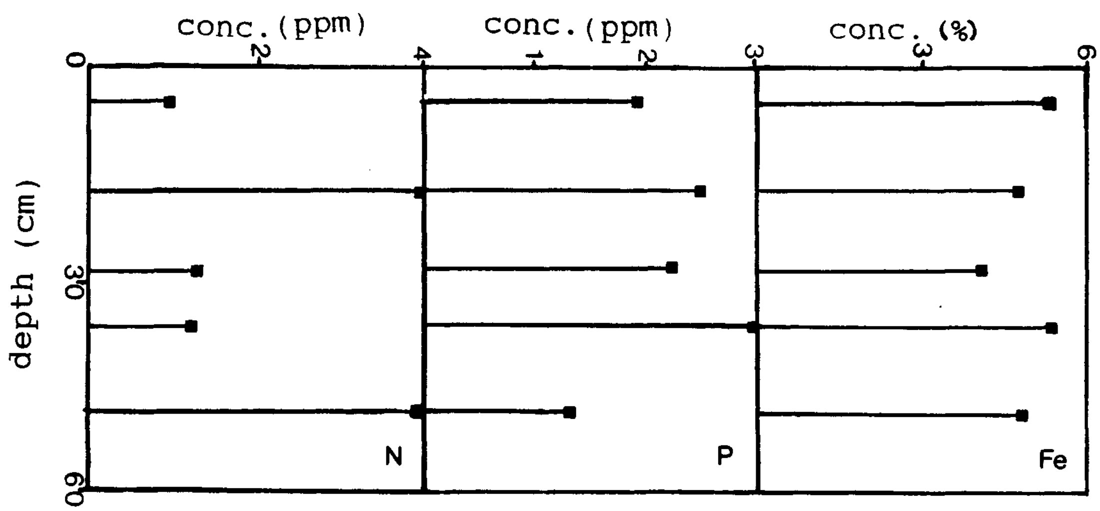

Fig. 3.1b. Concentrations with depth, revegetated slope

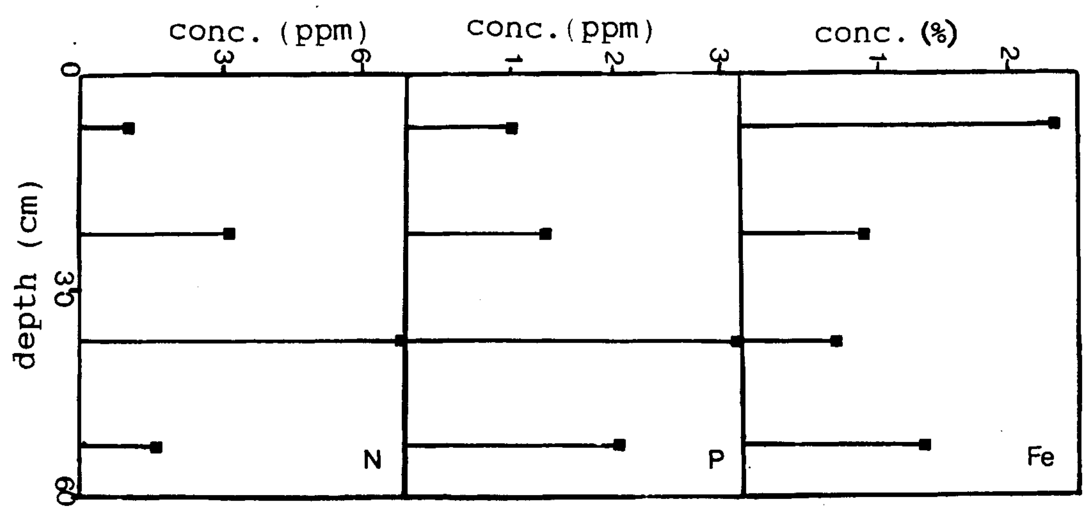

Fig. 3.1c. Concentrations with depth, forest slope

20 cm thick A horizon is a sandy loam, of medium blockiness with bits of organic matter in it and has a dry soil colour of 5YR 6/6. The 24 cm B horizon is a silty sand with a dry soil colour of 5 YR 5/8. The subsoil layers appear to have more clay in them the further upslope the sample is taken. The pH of the soil is 4.33 and the nutrient concentrations with depth are given in Fig.3.1b.

3.1.3 Soils from areas experiencing slight erosion

These are the heavily vegetated areas usually on the north-facing slopes (although SW3 and SW4 are located on an east-facing slope). The first example considered here, the forested slopes, covered a range from well-defined horizons to quite undefinable horizons within a short distance of each other. The following is a description of the soils from the slope on which SW3 and SW4 are located. The O horizon is 10 cm thick, loamy in texture with a dry soil colour of 5 YR 5/4. The 20 cm thick A horizon is a clay loam containing some stones. The dry soil colour is 5 YR 6/6. The subsoil layer is a clay and the dry soil colour is 7.5 YR 6/6. The pH of the soil is about 5.0 and the nutrient composition is given in Fig.3.1c.

SF1 to SF5 were located on a fern-covered slope. The O horizon, about 6 cm deep, is sandy in texture with plenty of undecomposed roots and twigs. The dry soil colour is 10YR 4/3. The A horizon is inverted, a loamy sand with a crumbly structure and some organic matter. The dry soil colour is 5 YR 6/6. The subsoil is a well-drained loamy sand. The soil pH is 4.24 and the nutrient content is given in Fig.3.1d. The top 25 cm are rich in potassium while the subsoil appeared iron-rich. The other nutrients did not vary much with depth.

3.2 Discussion

3.2.1 Elemental trends

Total aluminum was present in very high concentrations (analytical error ± 1%) in the soils (Fig.3.2a) and available aluminum would probably be high also because the soils are so acidic. In turn, as more aluminum becomes available through hydrolysis, the pH would be further depressed (Section 1.2). This dominance of one element in the soil matrix caused difficulties during neutron activation because the high activity from the aluminum isotope raised the background levels and obscured the other elements. Acid soils such as those prevailing at the Shenchong basin also show high levels of available iron compared to the other nutrients. Given the age of the soils, however, much of the soluble iron has been removed. Available iron appeared to be concentrated in the subsoil layers. These cations would form complexes with free phosphate ions which are already in short supply in this

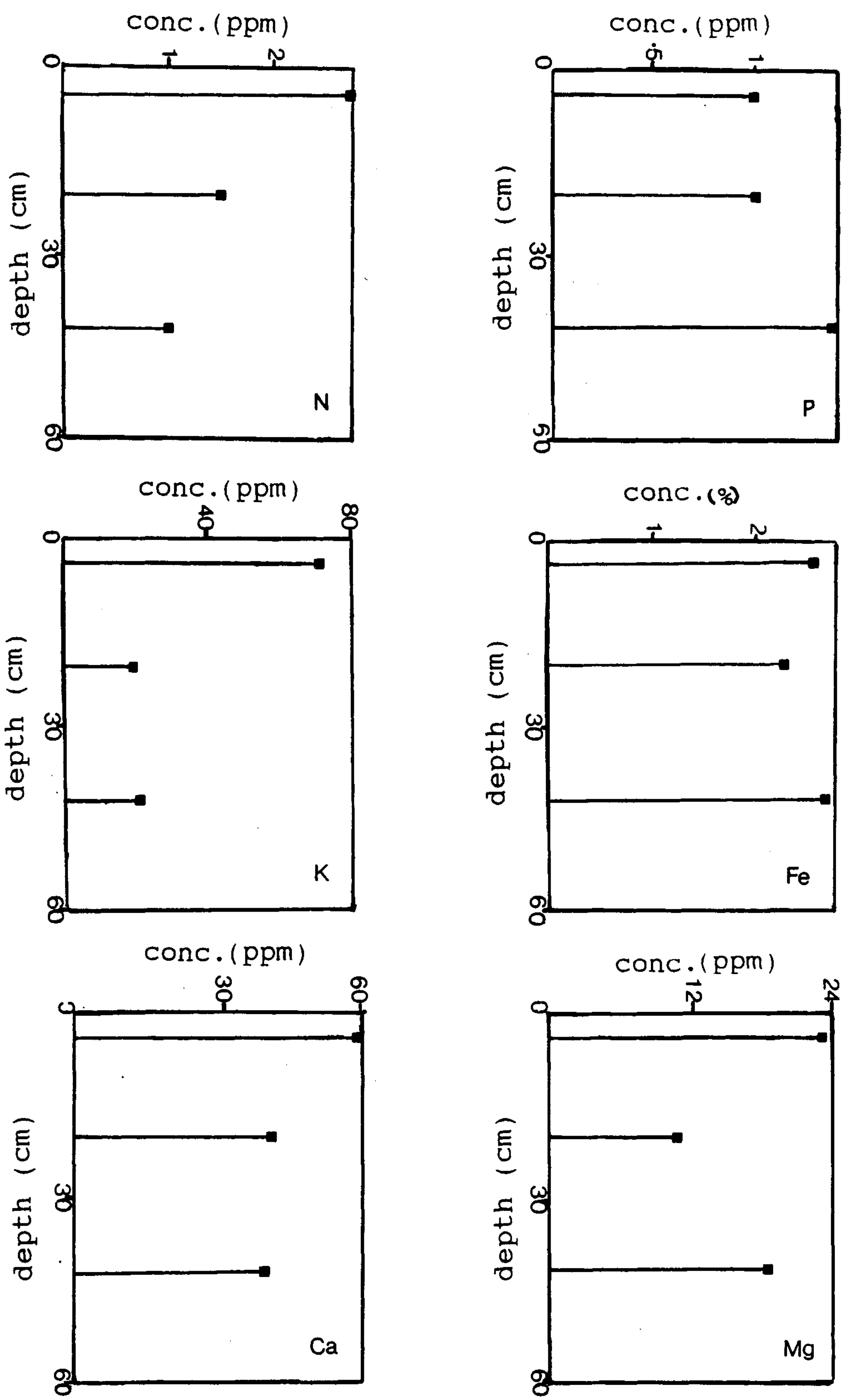

Fig. 3.1d. Concentrations with depth, fern slope

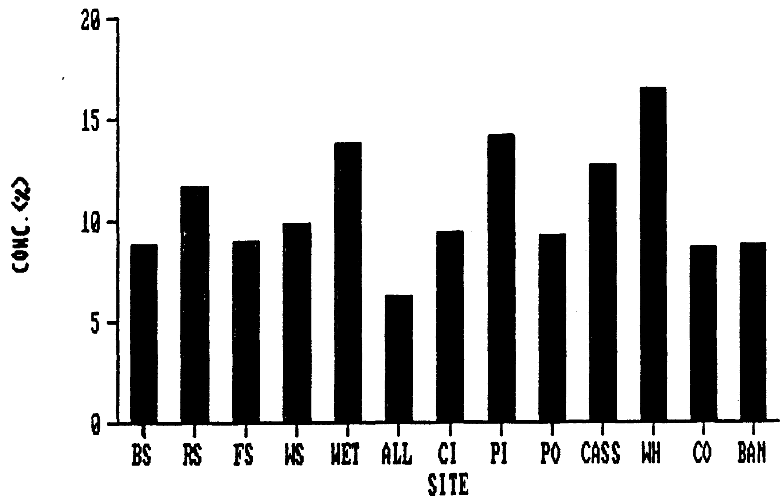

Fig.3.2a Total aluminum concentrations in Shenchong Basin soils.

LEGEND

BS	Bare slope
RS	Revegetated slope
FS	Fern slope
WS	Wooded slope
WET	Wetland
ALL	Alluvium
COLL	Colluvium
CI	Citrus field in tributary valley
PI	Peanut field in tributary valley
PO	Peanut field on former floodplain
CASS	Cassava field
WH	Baji field
CO	Citrus field on former floodplain
BAN	Banana field

basin, thus fixing the phosphate in an insoluble form unavailable to plants (Section 1.2).

Unlike phosphate, free nitrogen ions are relatively stable in solution (Walsh and Beaton, 1973). Nitrate is generally the predominant form of inorganic nitrogen in the case of well-aerated soil (such as those on the slopes) but it was not so in this study. Ammonium is probably the predominant form of inorganic nitrogen at Shenchong Creek. This would certainly explain the higher ammonium to nitrate ratio in the surface runoff (Section 3.6). Unfortunately, no tests for ammonium could be carried out since samples were air-dried prior to being brought back to Canada. Thus, whatever ammonia was present would have been lost through volatilization.

The parent rock is a major source of potassium. In Shenchong Basin the parent rock is biotite granite. It is abundant in orthoclase, and when weathered releases much potassium into the surrounding soils. Magnesium levels are low to moderate as most of this nutrient would have been leached from the soils due to the high acidity.

3.3.2 Interslope comparison

Vegetation appeared to make a difference for some of the nutrient levels. This difference is most conspicuous when comparing the bare slope with the vegetated slopes. The bare slope also had the lowest pH (Fig.3.2b) which

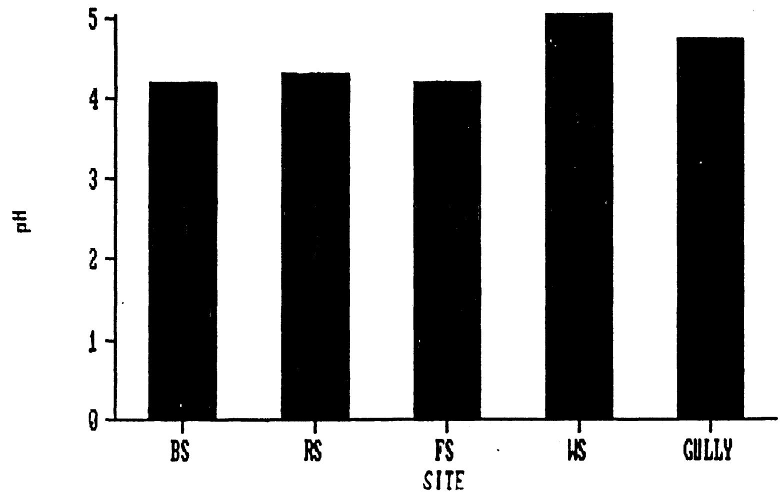

Fig. 3.2b. Soil pH.

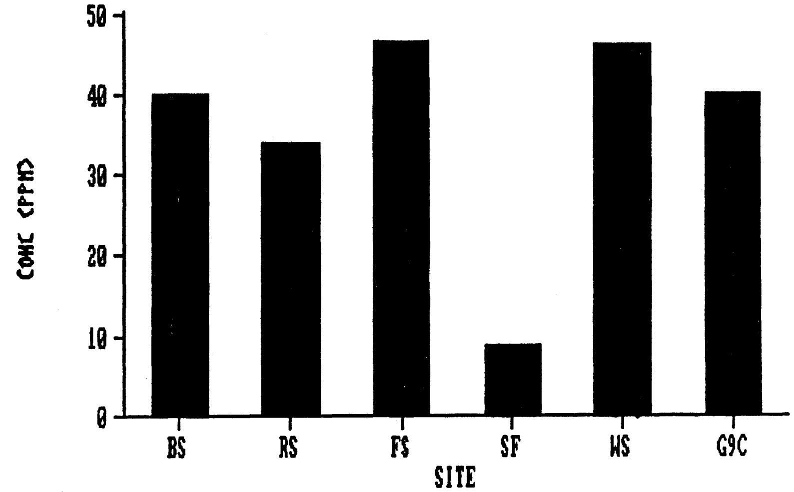

Fig. 3.2c. Soil calcium concentrations.

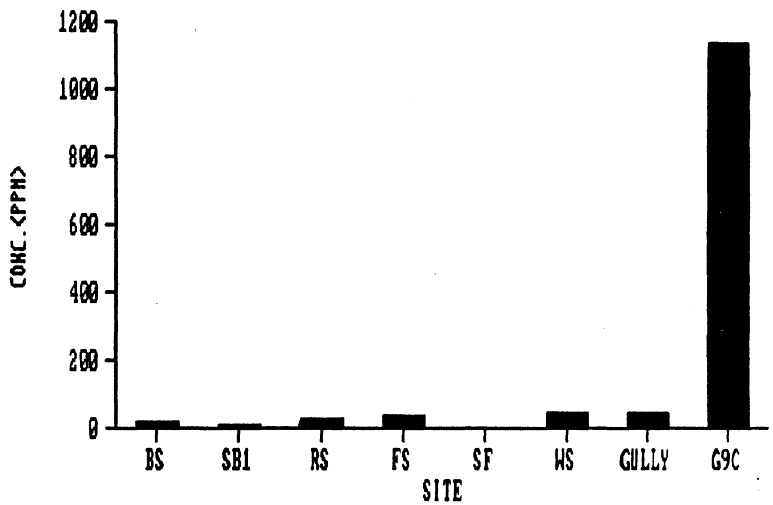

Fig. 3.2d. Soil potassium concentrations.

LEGEND

BS	Bare slope (soil)
RS	Revegetated slope (soil)
FS	Fern slope (soil)
WS	Wooded slope (soil)
GULLY	Gully Wall (soil)
SB1	Sediment from surface erosion plot on bare slope
SF	Sediment from surface erosion plot on fern slope
G9C	Sediment from gully G9C

could partially be attributed to the acidic pine needles (FAO,1978). The notable exception was calcium which was generally similar for all the slopes (Fig.3.2c). The most significant difference was in potassium levels, with the highest level at the wooded site, then the fern site, followed by the revegetated slope and finally the bare slope (Fig.3.2d). The potassium level in the gully wall was similar to that at the wooded site. Magnesium was highest at the wooded site but showed little variation at the other three sites (Fig.3.2e).

The iron level at the revegetated site was high when contrasted to the other slopes, a feature that may be related to the higher silt and clay content at this site (Fig.3.2f). The bare slope had the lowest level of available iron, possibly because the severe erosion it is subject to removes much of the iron released by weathering. Sediment from the bare slope had quite a high level of iron. Available phosphorus was highest at the fern site but the site-to-site variation is not very big (Fig.3.2g).

Finally, in considering nitrate levels in the soils, the wooded, revegetated and fern sites had higher levels than the bare slopes (Fig.3.2h), probably due to a higher degree of organic matter from plant litter (Wooldrige, 1968). It is also worth noting that higher nitrate levels were found in the lower horizons, which

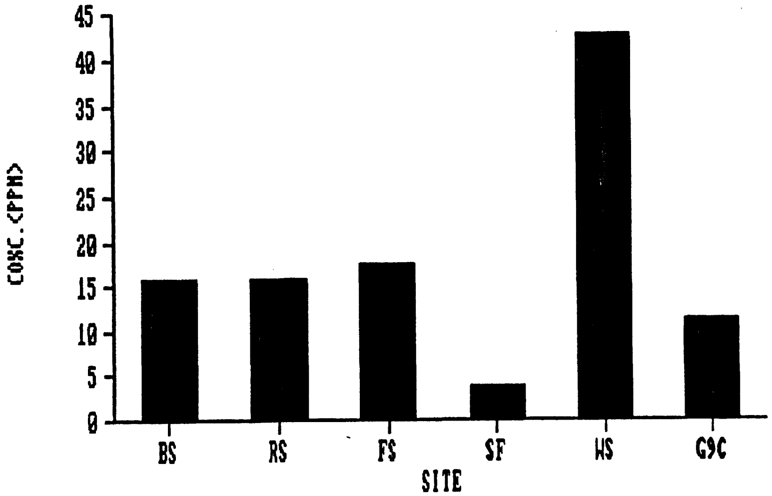

Fig. 3.2e. Soil magnesium concentrations

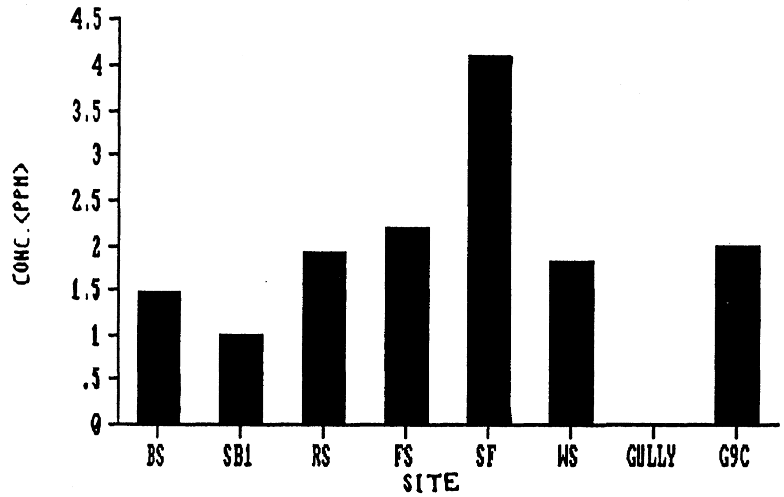

Fig. 3.2f. Soil available phosphorus concentrations

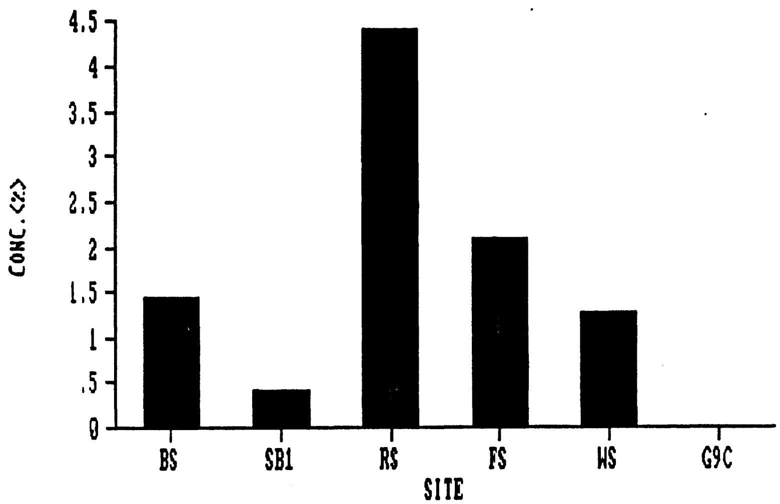

Fig. 3.2g. Soil iron concentrations

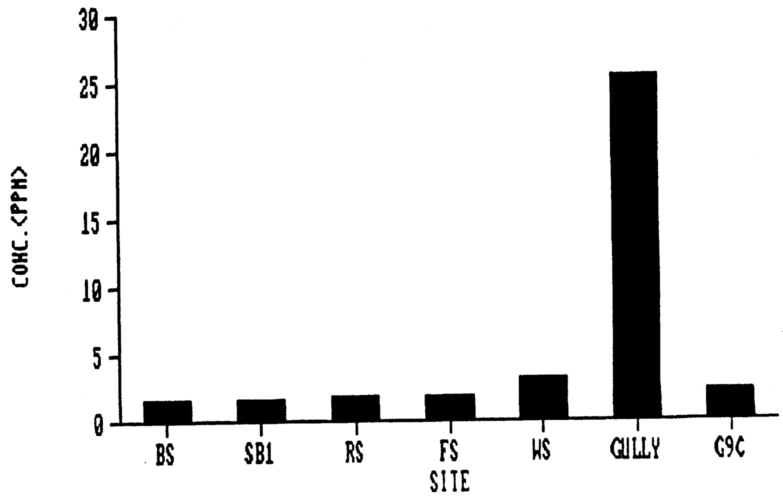

Fig. 3.2h. Soil nitrate concentrations

points to the influence of leaching.

Maintenance of nutrients within a vegetated ecosystem is closely tied to the maintenance of the nutrient cycle. Systems that have been disrupted (such as by partial removal of the fern cover) can recover but repeated disruptions will lead to severe damage of the ecosystem, an example being the bare slopes.

3.3 Sediment Nutrient Levels

Sediment nutrient levels from gully G9C, SB1 and the fern plots are also shown in figs.3.2a,b,c,d,e and f to allow comparison between the soils and the sediment exported. The gully sediment from G9C was rich in potassium, average in calcium, nitrate and phosphate, and low in iron content -- similar to the 'soil' levels, except for nitrate which was lower. The high level of nitrate in the gully wall is probably due to leaching (Section 4.1.1). The colluvial sample showed a very high level of nitrate. Kinjo and Pratt(1971) explain this as due to nitrate being absorbed from runoff onto the aluminosilicate sand grains.

The abnormally high potassium content could be due to contamination of one of the samples that went to making up the grab sample, in which case a likely source would be the ash from burnt vegetation washed out in the rain. Samples from the gully walls show a moderate level of extractable potassium (Section.3.2.1), but colluvium samples show a very high level of potassium (Section 4.1.1). It appears that the gully floor is acting as a sink for the potassium (and possibly, the nitrate) from the surrounding vegetated areas. Jehne (1981) suggested that potassium is trapped in a sesquioxide coating on the sand grains.

Sediment samples from the bare plots showed similar levels of nitrate, phosphate, potassium and iron as the 'soil' samples from the slope. In contrast, nutrient levels in sediment from the fern slope differed from soil nutrient levels. Phosphate level in sediment was higher than that found in the soil, possibly due to enrichment from the runoff (Sharpley,1980). However, potassium, calcium and magnesium levels were significantly lower than the soil levels. Mengel and Kirkby (1979) noted that the presence of organics in sediment influences the adsorption and desorption of nutrients. Moreover, vegetation acts as a filter taking up certain nutrients from water (runoff and soil water) very quickly. More research is needed in order to understand the role of vegetation as a potential source of enrichment as well as a nutrient filter for runoff. A detailed discussion of the significance of the nutrient levels in the upland soils and sediment, in the context of the nutrient status of the whole basin, will be presented in chapter 4.

3.4. Meteorological Data

3.4.1 Temperature and precipitation data

The summer of 1987 was relatively dry. Comparison of monthly rainfall totals for June, July and August to average monthly totals calculated from the 20-year Deqing county record show that rainfall in June was was 50% less than average, July received 25% more and August recieved 25% less than average (Munro and diCenzo, 1987). Air temperatures in early June were lower than normal while temperatures in July and August were above normal (table 3.1).

3.4.2 Precipitation chemistry

In forested watersheds where no fertilizer is used, rainfall may be an important source of nutrients (Likesn et al.,1977; McClurkin and Duffy,1987). However, Sharpley and Syers (1979) contend that nutrients in runoff mainly originate from the soils and vegetation. Rainfall on July 29 had relatively high ammonia and on July 30 had relatively high phosphate (Table 3.2). Since slash-burning is practised in the region airborne particles may be the cause of these higher concentrations. In order to test for the effects of leaching by stemflow, samples were also collected from shallow pans placed underneath different vegetation canopies. Nutrient concentrations were low except for potassium. This is because potassium does not form an integrated unit in plant matter and can easily be

Table 3.1 Monthly precipitation totals and average temperatures at Shenchong Basin compared to the 20-year average at Deqing.

Month	Shenchong Basin precipitation (mm)	Deqing precipitation (mm)	Shenchong Basin temperature (^0C)	Deqing temperature (^0C)
June	103	213	27.5	26.5
July	199	157	28.3	27.0
August	149	208	28.4	27.5

Table 3.2 Nutrient concentration in rainfall and throughfall samples at Shenchong Basin.

Date	Gauge	NH_4^+ (ppm)	NO_3^- (ppm)	PO_4^{3-} (ppm)	Fe^{3+} (ppm)	Ca^{2+} (ppm)	K^+ (ppm)
22 July	B1	.56	.04	.03	-	-	-
29 July	B1	1.00	-	-	-	-	-
30 July	B1	-	-	.23	1.46	.11	ND
8 August	B2						
	I1	ND	.35	.03	.43	1.59	3.90
	I2	-	.37	.01	-	-	-
	I3	-	.35	.01	.51	.97	8.34
9 August	B1	.1	.12	.03	-	-	-
	B2	.33	ND	.02	.14	.36	.4
	I1	.33	.05	.01	-	-	-
	I2	.33	ND	ND	-	-	-
	I3	.08	ND	ND	.14	.19	2.64
11 August	B2	ND	.07	.01	-	-	-
	I3	Nd	.14	.04	-	-	-

B1 Bulk precipitation collector in front of farmhouse
B2 Bulk precipitation collector on fernslope
I1 Throughfall pan under pine trees
I2 Throughfall pan in undergrowth
I3 Throughfall pan under trees on reforested slope

washed off (Puckett,1987).

3.5 Surface Runoff

Surface runoff data were collected during late July and early August. Most of the samples were collected from the fern plots (SF1 to SF5), bare plots (SB1,SB2), rills (R5, R6) and gully G9C. Occasional samples were obtained from the forested plots SW3 and SW4 which, in any case, produced little runoff and minimal sediment.

3.5.1 Total yields for discharge and sediment

Simple linear regresion was used to investigate the relationship between rainfall and total runoff:

$$q = b_0 + b_1 r \qquad (4)$$

where b_1 indicates the portion of the rainfall available to runoff and b_0 represents the initial losses to wetting the vegetation and soil, in which case b_0 should realistically be negative. Discharge values are expressed in runoff per unit area and the results of the regressions are given in Table 3.3. Part of the difficulty of obtaining good relationships is because runoff is also dependent upon antecedent moisture conditions for which there are no measurements in this study. A chi-squared test between discharge per unit area for SB1 and SB2 on the same day yielded a value of 1.44, implying that there was no statistically significant difference in the response of the two plots despite the presence of a layer of pine needles

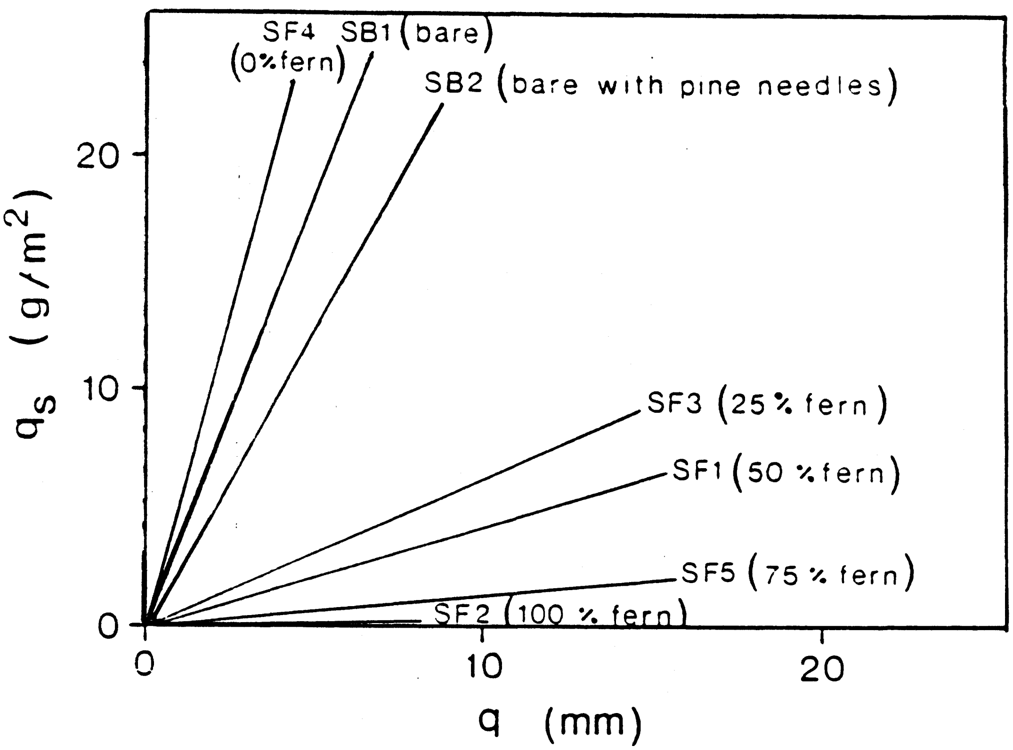

Fig.3.3 Relation of sediment load (q_s) and runoff (q) for six surfaces (Woo and Young,1987).

Table 3.3 Relationship between rainfall (r) and overland flow (q) based on linear regression $q = b_0 + b_1$ (Woo and Young,1987).

Plot	Cover conditions	b_0	b_1	Correlation Coefficient	Degrees of Freedom
SB1	Bare	-1.694	0.557	0.86**	13
SB2	Bare	-0.783	0.464	0.94**	15
SF4	Stripped, 0% cover	-2.956	0.487	0.93**	9
SF3	Fern, 25% cover	-0.422	0.091	0.84**	12
SF1	Fern, 50% cover	-0.022	0.027	0.81**	13
SF5	Fern, 75% cover	-0.214	0.042	0.76**	12
SF2	Fern, 100% cover	+0.030	0.006	0.79**	11

**significant at 0.99 probability
*significant at 0.95 probability

on plot SB2. In the case of the fern plots which offered a range of cover conditions, the b_1 value increased as the portion of the fern cover decreased implying that overland flow is much reduced by the presence of plant cover (Woo and Young,1987).

3.5.2 Sediment yield

Woo and Young (1987) compared the relationship between sediment load and runoff from the fern and bare surface plots. They concluded that the presence of vegetation effectively reduces the availability of sediment for entrainment. One point that should be added is that SF4 actually showed higher sediment concentrations than SB1 and SB2 (Fig.3.3). This is due to a larger amount of loose sediment on the recently stripped plot, suggesting that areas that have been completely stripped of their covering would very quickly lose topsoil. The beneficial role of vegetation was also reinforced by the low sediment losses from the vegetated rill (R6) compared with the bare rill, R (Woo and Young,1987).

3.6 Nutrient Concentrations in Surface Runoff

Nutrient concentrations were monitored for the storms of July 22, 24, 28 and 30 as well as August 9 and 11 in 1987. Rainfall data for these storms are presented in Fig.3.4. The storms of August 9 and 11 were intensely

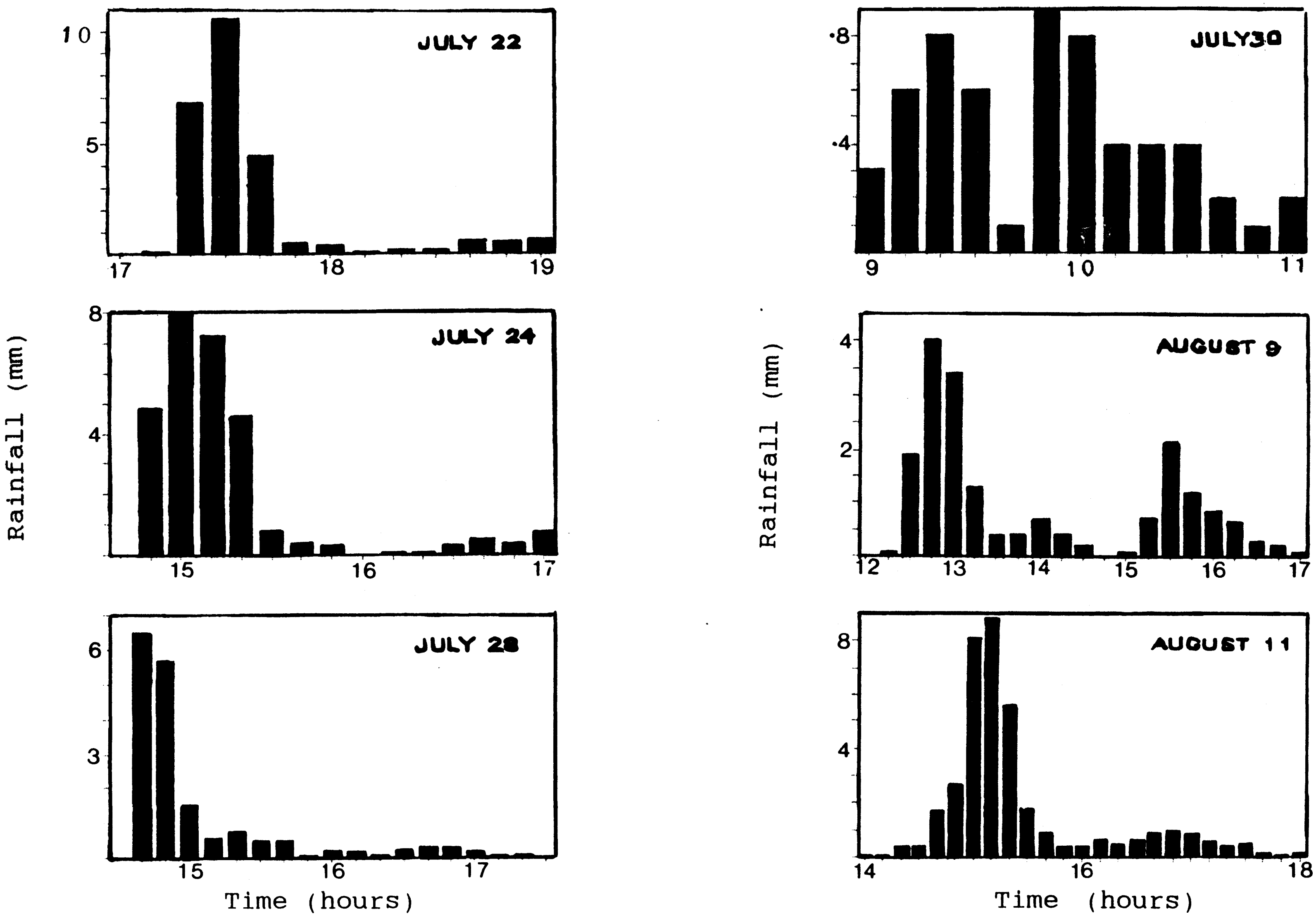

Fig.3.4 Rainfall data for the storms of July 22, 24, 28 and 30 and August 9 and 11 1987

monitored in order to get descriptive profiles of nutrient response at different sites. Although attempts were made to obtain samples at regular intervals thoughout the storm, in some cases this was precluded by the shortage of labour. At the forested plots and the more densely covered fern plots, discharge was so slight that one or two samples per plot were sufficient to cover the entire storm. The following sections will describe the temporal variation of nutrient concentrations in the surface runoff from the plots.

July 22

The storm of July 22 deposited 32.5 mm of rain on the basin. At SB1 potassium showed the highest concentration (3 ppm) and its importance persisted throughout the two-hour period for which data were collected. Iron peaked at 2.4 ppm before the period of maximum rainfall intensity and then dropped off to below .5 ppm. Calcium concentration fluctuated between 2.5 and 1.5 ppm. Ammonium levels registered approximately .5 ppm and nitrate levels were lower starting at .175 ppm early in the storm and then falling below .1 ppm later on. Orthophosphate concentrations were extremely low at less than .05 ppm. In the case of the low values for nitrate and orthophosphate it was difficult to distinguish the true levels from the background noise. The relative uncertainty associated with the observations is ± 10%. Data for this storm are given in the Appendix.

At SF5 Ammonia had relatively the highest concentration at 5.68 ppm, nitrate concentration was approximately .1 ppm and orthophosphate was negligible. SF3 and SF4 samples had ammonium levels at less than 1 ppm, nitrate levels were very low at less than .04 ppm and orthophosphate levels were insignificant. Levels of calcium and potassium were similar for the three plots, ranging from 2.5 to 3.0 ppm. SF4 showed very little iron, .07 ppm, compared to SF3 and SF5 which recorded 1.8 ppm and 2.3 ppm respectively. This difference may be due to the fact that iron could have peaked early in storm runoff and was missed by the sampling schedule at SF4 which had the most rapid response to rainfall of all the fern plots.

Potassium showed the highest concentration of all the nutrients in the samples from the forested plots SW3 and SW4, 8.4 and 4.1 ppm respectively. SW3 also showed a higher concentration of calcium than SW4, 3.9 as opposed to 1.3 ppm. This may be explained by contamination from the cement spilt in the plot by the builders during construction. A sample of the cement analyzed showed a composition of 2970 ppm calcium, 2 ppm phosphorus and 311 ppm potassium. Iron concentration was also higher at SW3 (2 ppm) than at SW4 (1.1 ppm). Only data from SW4 are available for ammonium, nitrate and orthophosphate. Concentration of ammonia was low at .8 ppm and even lower still was the concentration of nitrate at .03 ppm, while orthophosphate was non-detectable.

Concentrations of potassium, calcium and iron were similar at R5, the bare rill plot; potassium levels ranged from 1 to 2 ppm, calcium ranged from 1 to 3 ppm and iron, between 1.4 and 2.0 ppm. Due to the small number of measurements and the small range it was not possible to discern any temporal trend. Ammonium concentration was the highest of the macronutrients and at approximately 1.0 ppm it was almost ten times the level of nitrate. Orthophosphate concentration was very low at less than .05 ppm. No data were available for the vegetated rill, R6.

At gully G9C ammonium levels had the highest of the ions tested for, ranging from 6.4 to .7 ppm. Nitrate levels were almost ten times lower at .5 ppm. While the ammonium response fluctuated, nitrate levels were steady except for an initial peak. Orthophosphate levels were low ranging from .003 to .23 ppm. At the lowest levels it is possible that the concentrations recorded were masked by background noise. Calcium was consistently between 1.4 and 2.2 ppm. Iron peaked at the beginning and in the second half of the storm. Potassium concentration was consistent at about 1.0 ppm except for a peak late in the storm.

<u>July 24</u>

Potassium levels at SB1 were slightly higher than those of the previous storm, ranging from 2.5 to 5.0 ppm.

Calcium, iron and ammonium levels were similar to those on July 22. Nitrate concentration had increased (.1 to 0.2 ppm). Orthophosphate was insignificant except for one burst at .3 ppm. All data for this storm are in the Appendix.

SF4 showed a high concentration of ammonium, 2.3 ppm early in the storm, supporting the previous statement that ammonium may be lost early in the storm. Nitrate was ten times less than ammonium and orthophosphate was negigible. Potassium concentration at SF4 was similar to the bare plots. Iron concentration dropped to one-tenth its early value later on in the storm. Calcium concentration ranged from .3-1.1 ppm.

At SW4, Calcium had increased to 7.2 ppm, but iron and calcium and nitrate were unchanged from the previous storm. Ammonium concentration was up to 1.6 ppm, over twice the value of the previous day.

At R5 potassium and ammonium concentrations stayed the same, but iron, calcium and nitrate were down from the previous storm. Orthophosphate was again insignificant except for one burst of .2 ppm.

At G9C potassium showed the highest concentration of all the ions, with a maximum of almost 8.3 ppm. Potassium showed two peaks. Iron and calcium levels were similar to those at the bare plots and the rills. Amonium levels were down from the storm of July 22 with a range of .5 to 1.2 ppm. Nitrate levels were reduced to .5 ppm and orthophosphate was low with a maximum of .12 ppm.

July 28

At SB2 potassium concentrations were high and consistant through time. Calcium and iron levels were similar to earlier storms. Iron peaked early at 3.5 ppm. Ammonium levels were low at around .35 ppm while nitrate was non-detectable. Orthophosphate levels were relatively high to begin with before falling to an insignificant level. Data for this storm are given in the Appendix.

The fern plots, SF1, SF4 and SF5 showed high potassium concentrations in the discharge although SF4 was at the lower end of the scale and SF1 had a low reading too at 1.54 ppm. This could imply the influence of vegetation, as SF4 was stripped of its covering. Ammonium levels were low at less than 1.0 ppm and nitrate and orthophosphate were negligible except for one relatively high value at SF1 of .47 ppm.

The concentration of potassium at R5 was low at approximately .7 ppm. Iron and calcium levels were similar to those on July 24 and iron decreased throughout the storm. Ammonium levels were again around .7 ppm and orthophosphate concentrations were extremely low at less than .01 ppm. No data were available for nitrate concentrations. At G9C maximum potassium concentration was

3.6 ppm which was higher than the other nutrients. Iron and calcium showed similer concentrations as well as trends. The peak iron concentration was 2.5 ppm and that of calcium was 2.0 ppm. Ammonium levels continued to decrease from previous storms with a maximum of 1.3 ppm early in the storm and then dropping to .5 ppm. In this storm nitrate levels were actually similar to those of ammonium. As in the case of the other plots, orthophosphate levels were relatively high with peaks as high as .5 and .65 ppm.

<u>July 30</u>

Discharge from SB2 showed very high potassium levels ranging from 5.0 to 7.0 ppm. Calcium levels were consistant with previous storms (1.0-2.0 ppm) but iron levels had decreased to approximately 1.0 ppm. This, again, may be due to an early flushing of iron in the storm since by the time samples were collected it had already been raining for 15 minutes. Both SB1 and SB2 experienced similar levels of ammonium (.5 ppm) and very little nitrate, approximately .1 ppm. Orthophosphate concentration was undetectable except that both SB1 and SB2 showed prominant bursts of phosphate, .5 ppm and .3 ppm respectively. Data for this storm are given in the Appendix.

Both R5 and R6 showed similar levels of ammonium, nitrate and orthophosphate. Ammonium concentration varied around .6 ppm and nitrate concentration was low under .1

ppm. Orthophosphate concentration was low, but both R5 and R6 experience a surge at .2 ppm. Since the concentration of orthophosphate in the rainfall was high, .27 ppm, perhaps the high levels in the runoff could be attributed to this. R6 had slightly higher concentrations of calcium and iron compared to R5 but the real difference was in the potassium concentration. R6 had 5-8 times the concentrations found at R5.

August 9

At SB1 the most remarkable feature was the potassium peak at 22.0 ppm, halfway during the storm. Other discharge samples had consistent levels at 2.5-3.0 ppm. Iron concentration peaked early in the storm after which it fell to usual values, approximately .5 ppm. Calcium concentration ranged from non-detectable to 2.0 ppm with a temporal distribution characterized by peaks. Ammonium responded in surges with concentrations between .3 and 1.0 ppm. Orthophosphate was non-detectable except for one burst of .9 ppm in the first storm. No nitrate data were available for this storm as there was insufficient time to carry out all the tests. Levels of iron, calcium, potassium and ammonium, as well as temporal trends at SB2 were similar to those at SB1 except that the SB2 profile did not show the large potassium surge. Ammonium response lagged behind the other ions.

Orthophosphate was non-detectable (Fig.3.5ai and ii).

R5 showed similar levels of calcium and iron to those at SB1, but lower potassium. The major potassium peak arrived in the second storm of the day. R6 had similar ammonium levels to SB1 and R5 but the flushes came later. This could be due to the vegetation on the floor of the rill causing turbulence to volatilize the ammonia during the early part of the storm when discharge was high. Orthophosphate was negligible. Iron concentrations in the samples from R6 were lower than those from R5 and the decline was more gradual. Although potassium levels were similar (peaks at approximately 6.0 ppm), the temporal trend was reversed. At R6 the potassium peak arrived in the first storm while at R5 it arrived during the second storm (Fig.3.5aiii and iv).

At G9C ammonium and nitrate levels were reversed with nitrate concentrations now twice those of ammonium. However, nitrate concentrations had not changed much compared to earlier storms whereas ammonium concentrations had declined from previous levels. Orthophosphate was very low. Iron concentrations were low in the first storm and the profile was uneven. In the second storm it showed an early peak and then dropped off to ten times less than the peak value. Potassium showed two peaks (1.4 ppm) during the first storm. Calcium response was sporadic, between .05 to 1.65 ppm. In the first storm ammonium was flushed out

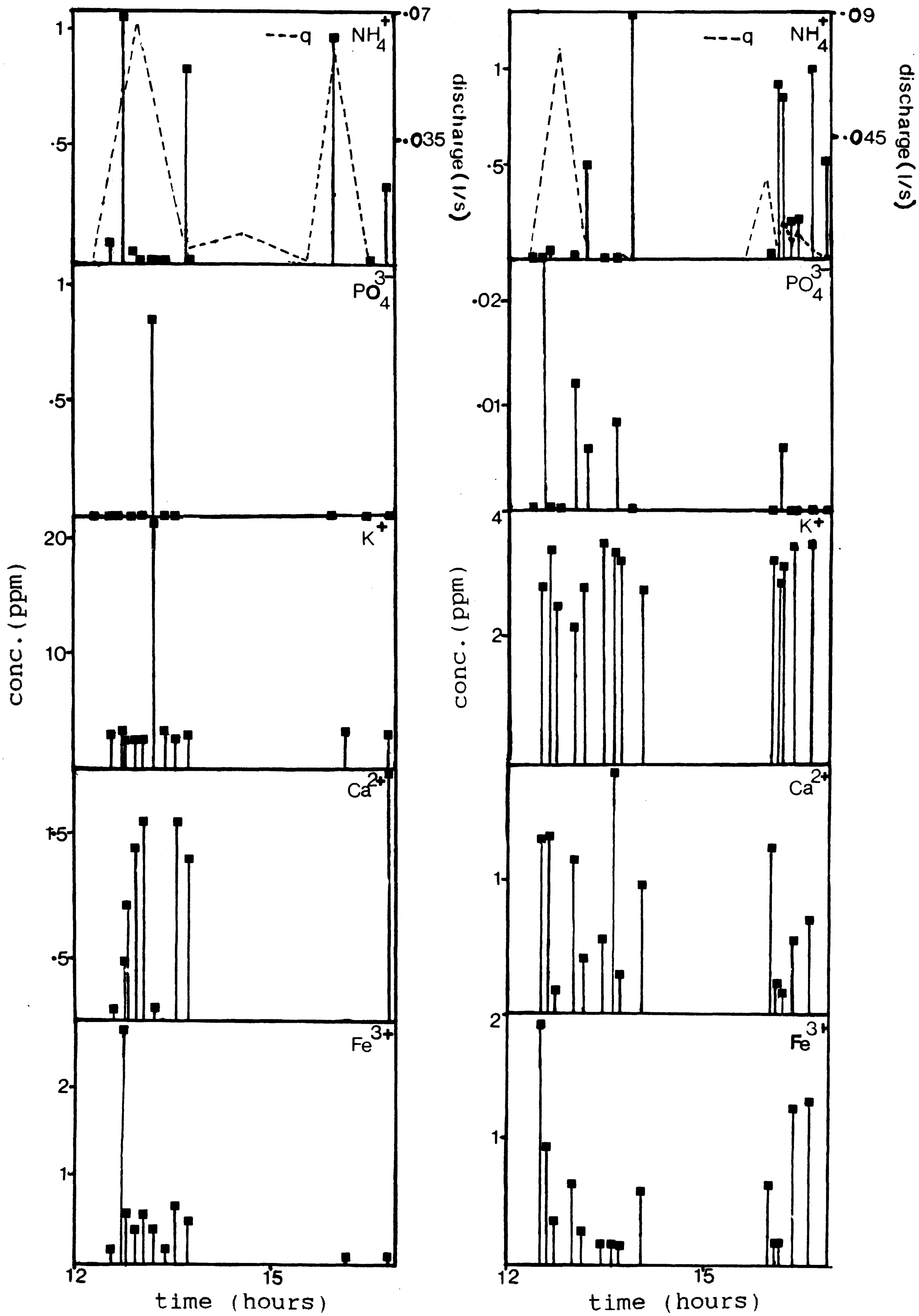

Fig. 3.5a i & ii. Nutrient concentration in runoff at SB1, SB2, August 9, 1987.

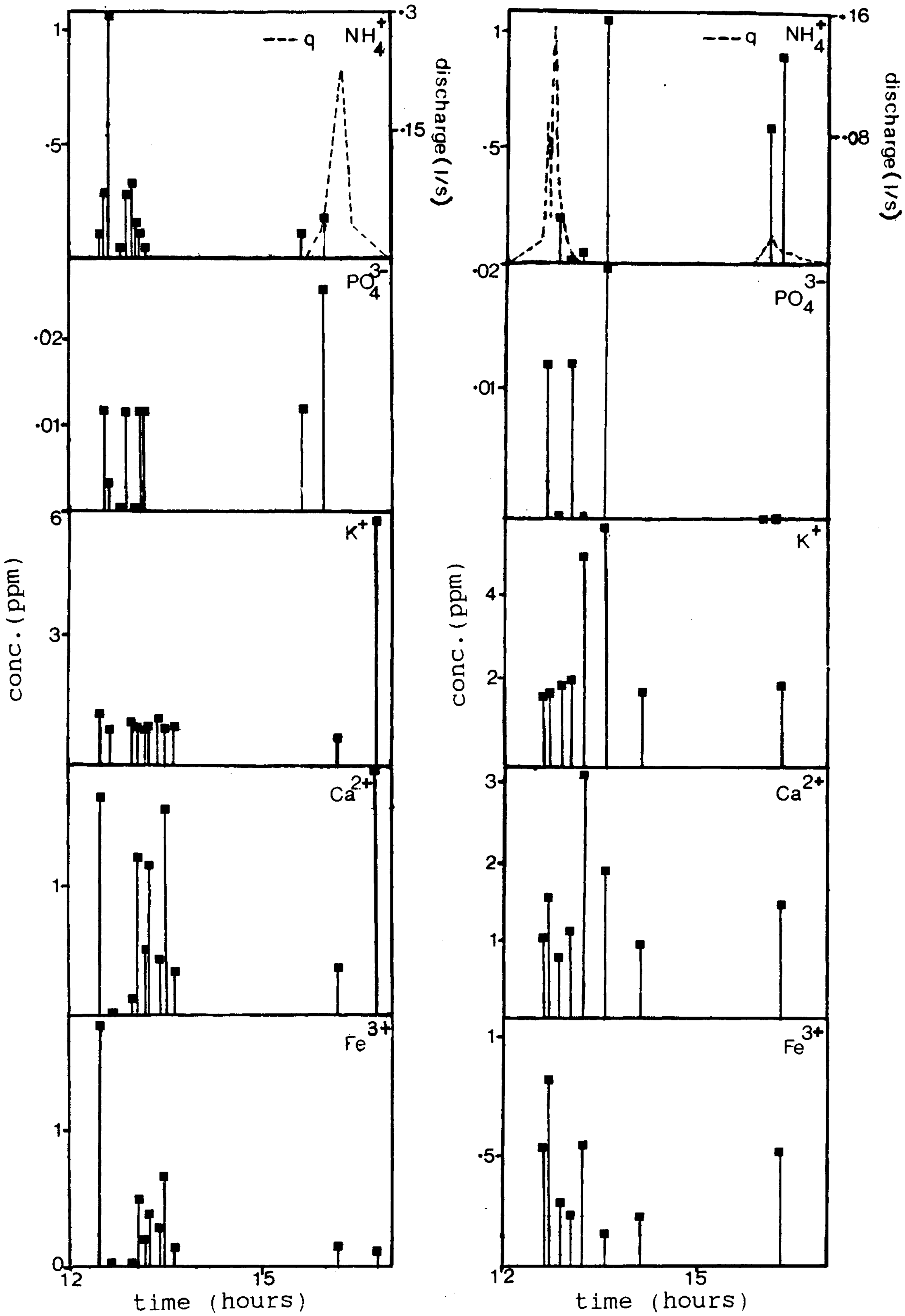

Fig. 3.5aiii.&iv. Nutrient concentration in runoff at R5, R6
August 9, 1987.

before potassium, followed by calcium and nitrate and then ammonium and orthophosphate. The opposite trend was observed in in the second storm (Fig.3.5av).

August 11

Nitrate concentrations at SB1 were low (less than .2 ppm) and orthophosphate was negligible. Tests for ammonium were not carried out for these samples due to lack of time. Nitrate response lagged discharge slightly (Fig.3.5bi). At SB2 nitrate response coincided with peak discharge but concentrations were about one-sixth the levels at SB1 (Fig.3.5bii). Again orthophosphate was negligible. Nitrate and orthophosphate levels at R5 were low and those at R6 were virtually undetectable (Fig.3.5biii and iv).

Concentrations of nitrate and orthophosphate at SF4, the stripped fern plot, were very low, less than .1 ppm and mostly undetectable. Concentrations at SF3 were undetectable as well (Fig.3.5bv and vi).

3.7 DISCUSSION

Certain trends can be generalized from the above data. The concentrations of the different ions in order of decreasing magnitude were: potassium > calcium > iron > ammonium > nitrate > orthophosphate. One exception was gully G9C, where ammonium was the most significant ion

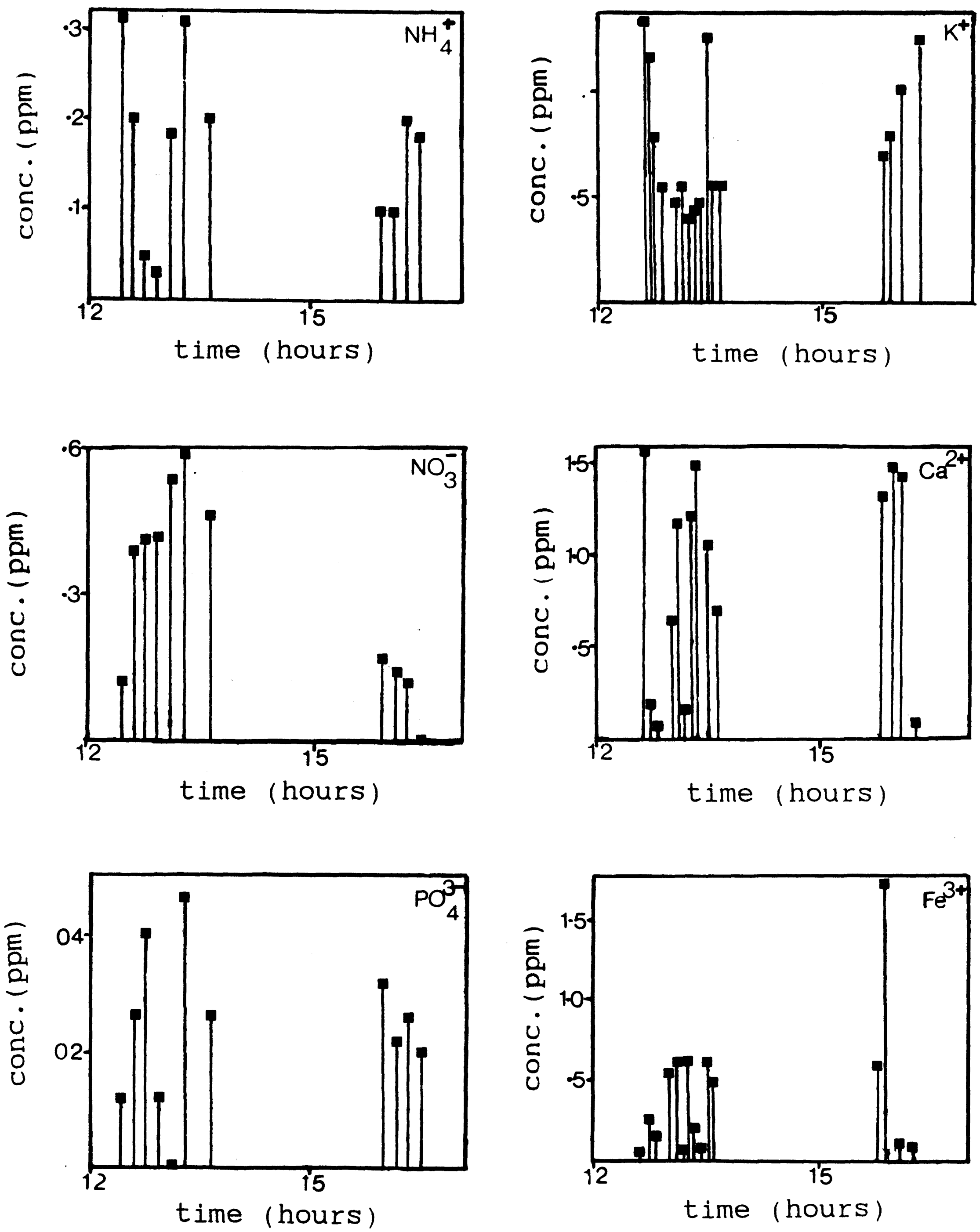

Fig. 3.5av. Nutrient concentration in runoff at G9C, August 9, 1987.

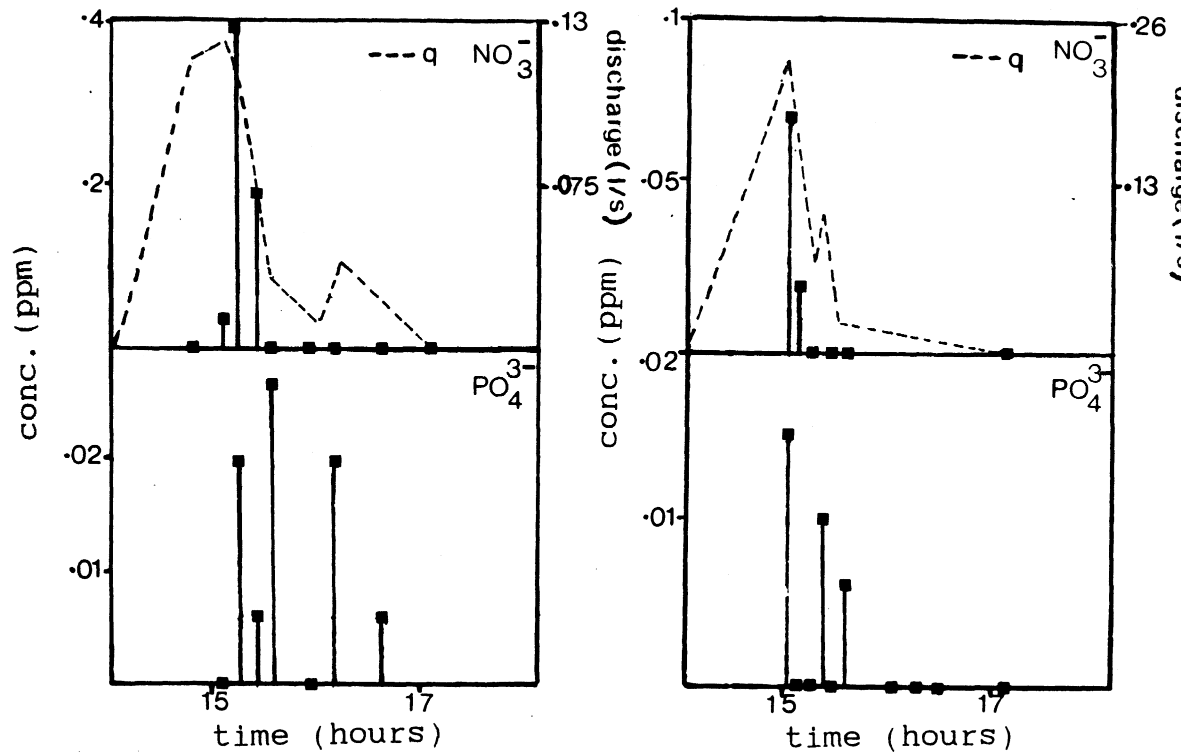

Fig. 3.5bi.&ii. Nutrient concentration in runoff at SB1 SB2 August 11,1987.

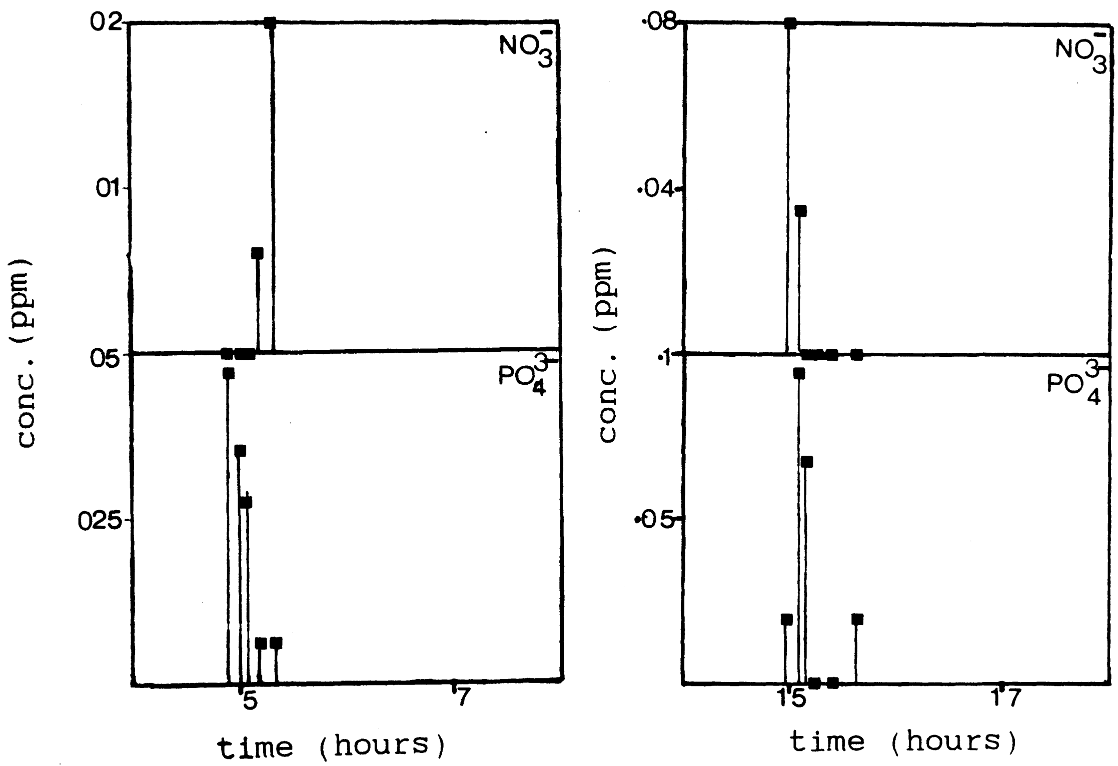

Fig. 3.5biii &iv. Nutrient concentration in runoff at SF3 SF4, August 11,1987.

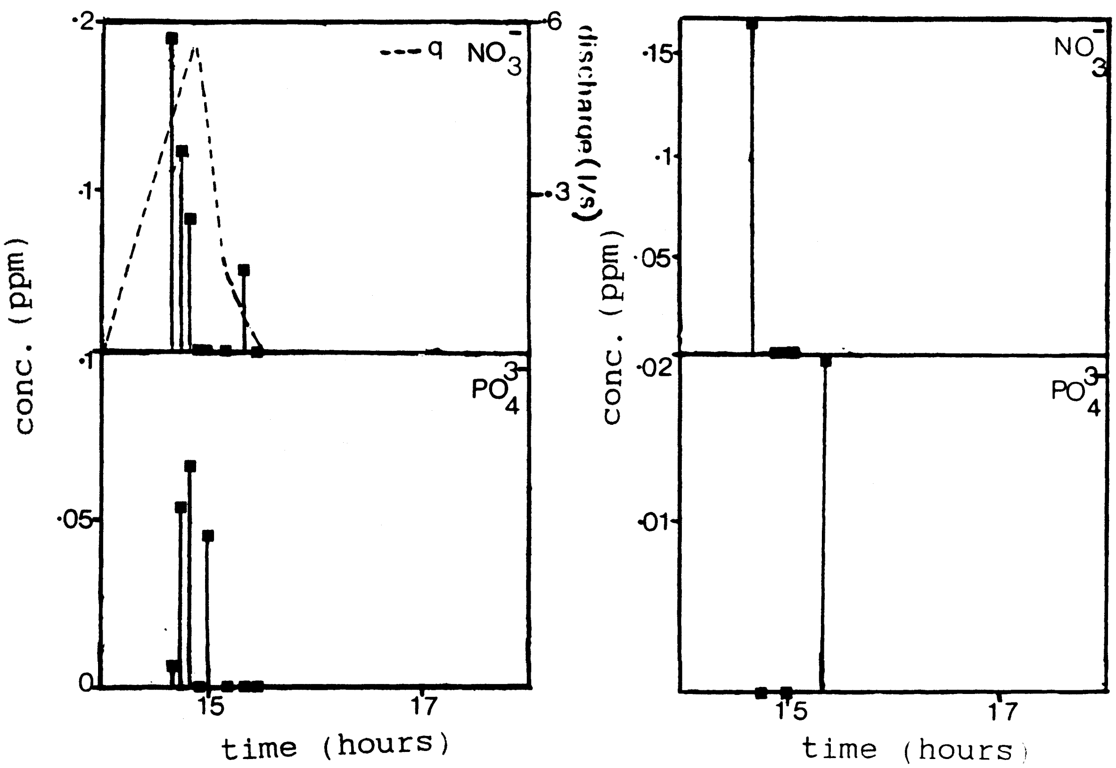

Fig. 3.5b v & vi. Nutrient concentration in runoff at R5, R6, August 11, 1987.

present during certain storms.

Potassium is very labile and given that the soil is rich in potassium it is not surprising that potassium concentration in surface discharge is also high. In addition, the analysis of the cement which was used to construct the plot boundaries showed evidence of potassium (311 ppm), phosphorus (2 ppm) and of course, calcium (2970 ppm). However, contamination from the cement should have produced a steady background concentration at all the plots. The steady calcium concentration levels in the discharge samples were probably due to contamination from the cement. The differences in potassium, then, could be attributed to the different levels in the soil. Soil potassium levels in turn imply the influence of different vegetation types and the extent of the vegetation cover (Kudeyarov et al.,1981; McClurkin and Duffy,1987). The presence of a biomass regulates erosion; in its absence nutrients are quickly washed out because of lack of uptake by vegetation (Likens,1985). Also, it is possible that some potassium might have been been leached from the vegetation because throughfall samples show higher potassium concentration than the rain above the tree canopy (Section 3.4.1).

Although available iron levels in the upland soils were high, concentration in runoff was moderate. Perhaps this is due to iron illuviation into the lower soil horizons, leaving less available iron on the surface to be washed away. If so, the concentration of iron in groundwaters should be higher than that in surface runoff. Judging from the few groundwater samples analyzed (Section 3.8), this was not the case. It is more likely that iron is lost mainly through sediment transport (Section 3.3).

Ammonium was the dominant form of inorganic nitrogen in runoff. The implications of this result for inorganic soil nitrogen have been previously dicussed in Section 3.3. It is worth noting that while nitrate levels did not vary much from storm to storm, ammonium levels did. This was especially relevant at G9C. A possible explanation is that ammonia volatilized from burnt vegetation remains in the atmosphere and is later washed out in the rain. Alternatively, ammonium is fixed to the clay particles and later washed out in the next rainstorm (Wetzel,1983). Ammonium concentration would then diminish after several storms due to washout, provided mineralization is not taking place at a faster rate. Hill (1985) and Webb and Walling (1985) observed that nitrate concentration was high after a dry period but decreased after several storms. Hence, the same phenomena could be taking place at Shenchong Basin where ammonium is the dominant form of mineral nitrogen. Webb and Walling (1985) also suggest that the decrease in inorganic nitrogen levels following a wet spell could be due to increased plant uptake. It has also been noted that ammonia volatilization in wet/dry regimes is very unstable as during wet periods ammonia goes into solution and can be washed out or else volatized during a subsequent hot, dry spell (FAO,1984).

Orthophosphate concentrations were negligible for most of the storms except for occasional bursts. Sharpley (1981) suggests that initial phosphorus losses come from plant leachings but this seems unlikely at this site since stemflow showed little phosphorus. Another possible explanation put forward by Ahuja et al. (1982) that phosphorus release is related to storm intensity and is more likely to be observed on bare slopes unprotected from rainsplash. This could have happened at G9C on July 28 and August 9, and at R5 and SB2 on August 11 but there is insufficient evidence to draw any conclusions. Sharpley (1981) and Cogger and Duxbury (1984) suggest that phosphorus release is controlled by aluminum and iron equilibria; if so, pH or oxidation conditions must have changed during the storm but there are no measurements for these parameters in this study. Since even these bursts are quite small and the cement contained a small amount of phosphorus, it is possible to explain these observations as contamination. Phosphorus is mainly transported through sediment which would account for the generally low orthophosphate concentrations (McColl,1974).

3.8 Nutrient Link between the Uplands and the Lowlands

At the start of this chapter it was mentioned that the uplands are a source of nutrients for the lowlands, through the transport of nutrients in surface runoff and sediment. The bare slope exports a great deal of sediment which is also the dominant vector of nutrient transport. The fern slope produces less runoff and sediment and the latter has a low concentration of nutrients. The gully exports a lot of sediment and the concentration of potassium is very high. Nitrogen is mainly exported as ammonium-nitrogen in runoff. Phosphorus is exported mainly as sediment.

The concentrations of nitrate, ammonium, orthophosphate, calcium, potassium and iron in surface water bodies, runoff and groundwater are similar; the exceptions are the ponds and the well at the entrance to the tributary valley (Table 3.4). The nutrient levels in the ponds can be explained by organic activity (fish, snails, algae etc.) and the high nitrate and orthophosphate concentration in the well is most likely the result of leaching and runoff of fertilizer from the fields on the terraces above the well. Since the source areas for nutrients are low in nutrients, the lowlands should have similar levels. The results of analysis of lowland soils and the comparison to upland soils is discussed in the next chapter.

Table 3.4 Nutrient concentration in surface and ground water samples collected from Shenchong Basin.

Location	NH_4^+	NO_3^-	PO_4^{3-} (ppm)	Ca^{2+}	K^+	Fe^{3+}
P1	-	-	-	3.00	3.23	.32
P2	.25	ND	ND	8.03	9.93	.35
P3	.40	ND	ND	1.81	1.55	.44
P4	2.00	.1	.03	2.70	6.06	.41
Stream x_1	.35	.04	ND	ND	1.29	2.70
x_2	.20	.03	ND	ND	.58	1.20
x_3	.15	.05	ND	ND	1.03	.66
x^4	-	-	-	1.74	4.52	1.81
Wetland	.18	.04	.53	.02	2.52	.91
Well at farmhouse	-	-	-	.56	1.94	.07
Well at the mouth of the tributary valley	.20	6.00	1.2	ND	2.06	.63
Groundwater well in the floodplain	.03	.04	-	1.30	1.29	.17

CHAPTER 4

THE LOWLAND ENVIRONMENT

Water, sediment and nutrients are transported from the upland areas during rainstorms and deposited on the lowlands. The latter consist mainly of the natural environment of colluvial fans, alluvial plains and wetlands, and the man-altered environment of agricultural fields and fishponds.

4.1 Soils

4.1.1 Soils in the natural depositional environment

In the natural depositional environment the coarse materials are deposited near the footslopes and the fines are carried further. The fine sediment consists of fine silts and clays which, when settled (usually in a depression), form a relatively impermeable layer. An infiltration experiment carried out at the colluvium underlain by a layer of fines showed that the infiltration rate was two orders of magnitude lower than that for the fern-covered slopes (Figs.4.1a and b). When a considerable thickness of clay has accumulated, infiltration is retarded, and eventually a wetland is formed. A sediment sample from a 30 cm pit in the wetland consists of a clay silt, with a Munsell dry soil colour of 7.5 YR 7/4. Its pH

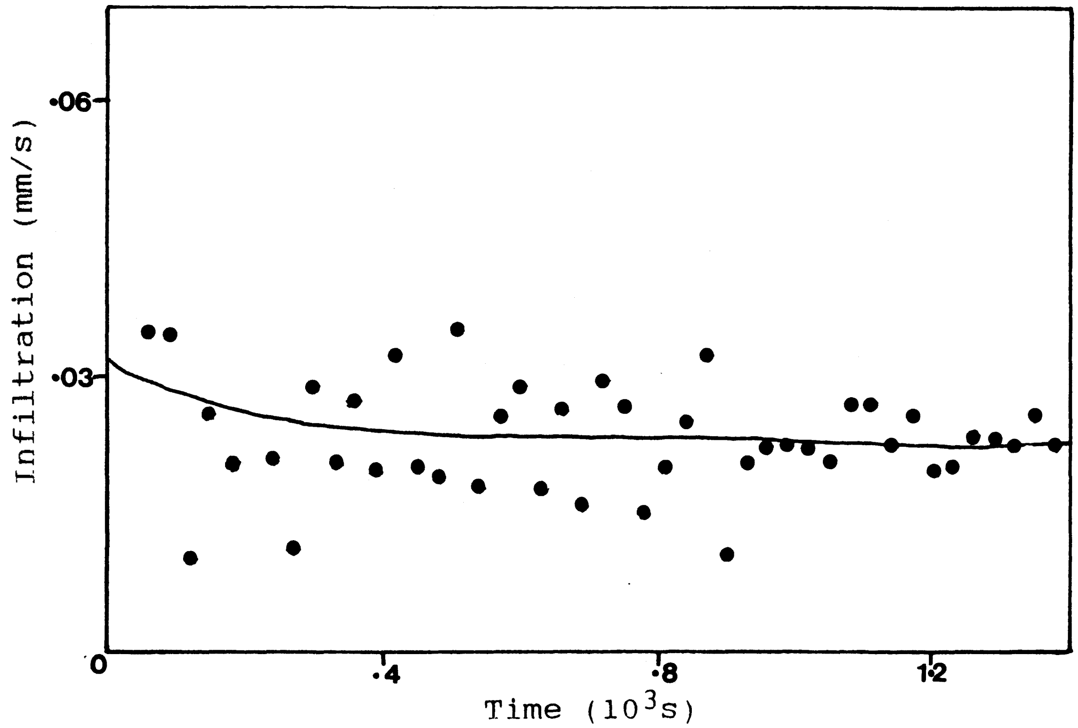

Fig.4.1a Rate of infiltration in the soil of the fern slope.

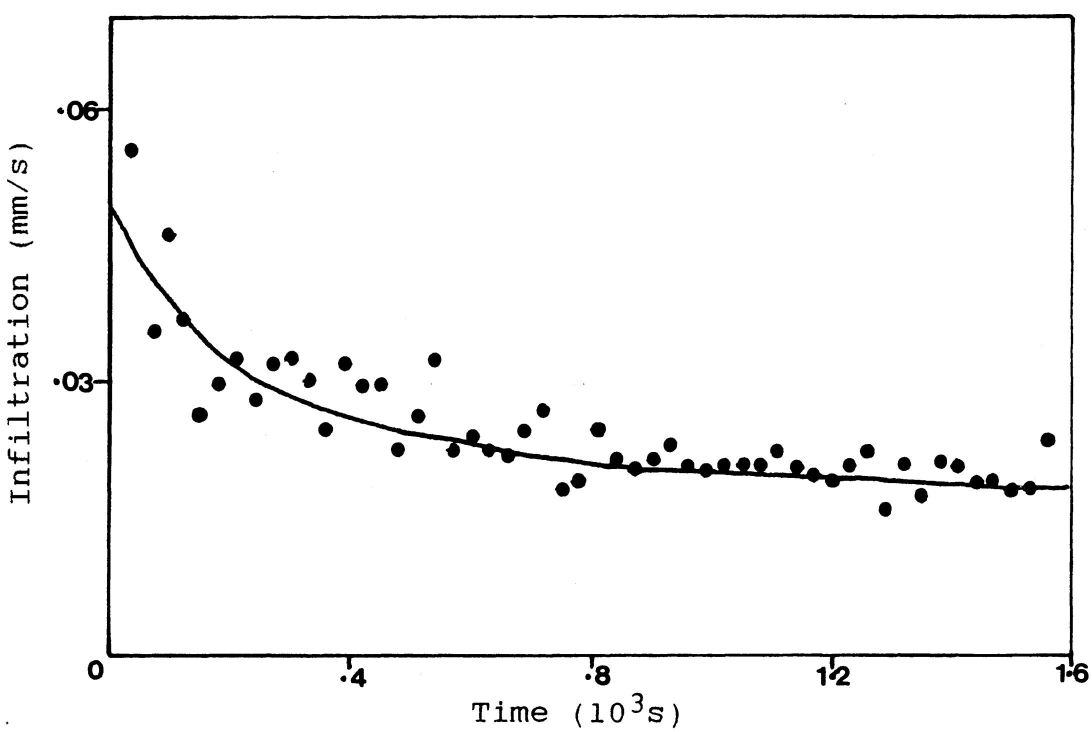

Fig.4.1b. Rate of infiltration in the soil of the citrus field.

is 5.24. The nutrient composition is given in Figs.4.4a,b,c,d,e and f and will be discussed in Section 4.3.

Debris and coarse sediment are deposited at the mouths of the gullies to form colluvial fans. These sediments are stratified but no soil horizons are apparent. The colluvium is sandy in texture with a Munsell dry soil colour of 5 YR 6/4. The soil pH is 4.4 and its nutrient composition with depth is given in Fig.4.2a (relative uncertainty associated with data points is ± 5%). The most notable feature is the sharp change in the nitrogen profile between the nitrate-poor top 20 cm and the nitrate-rich lower 25 cm. This may be attributed to the downward leaching of the nitrate.

During dry periods water in Shenchong Creek is shallow, about 4 cm deep, flowing along a narrow channel through the valley. During a heavy rainstorm there is a tenfold increase in depth and width. Sediment is transported from the slopes and colluvial fans and is deposited along the banks of the creek as alluvium. The coarser particles settle first while the finer particles are carried out to the wetlands. The sample taken from the alluvial floodplain has a sandy loam texture and a dry soil colour of 5 YR 7/6. Its pH is 4.61 and its nutrient composition is given in Fig.4.2b. In contrast to the colluvial fan the upper 20 cm of the floodplain are

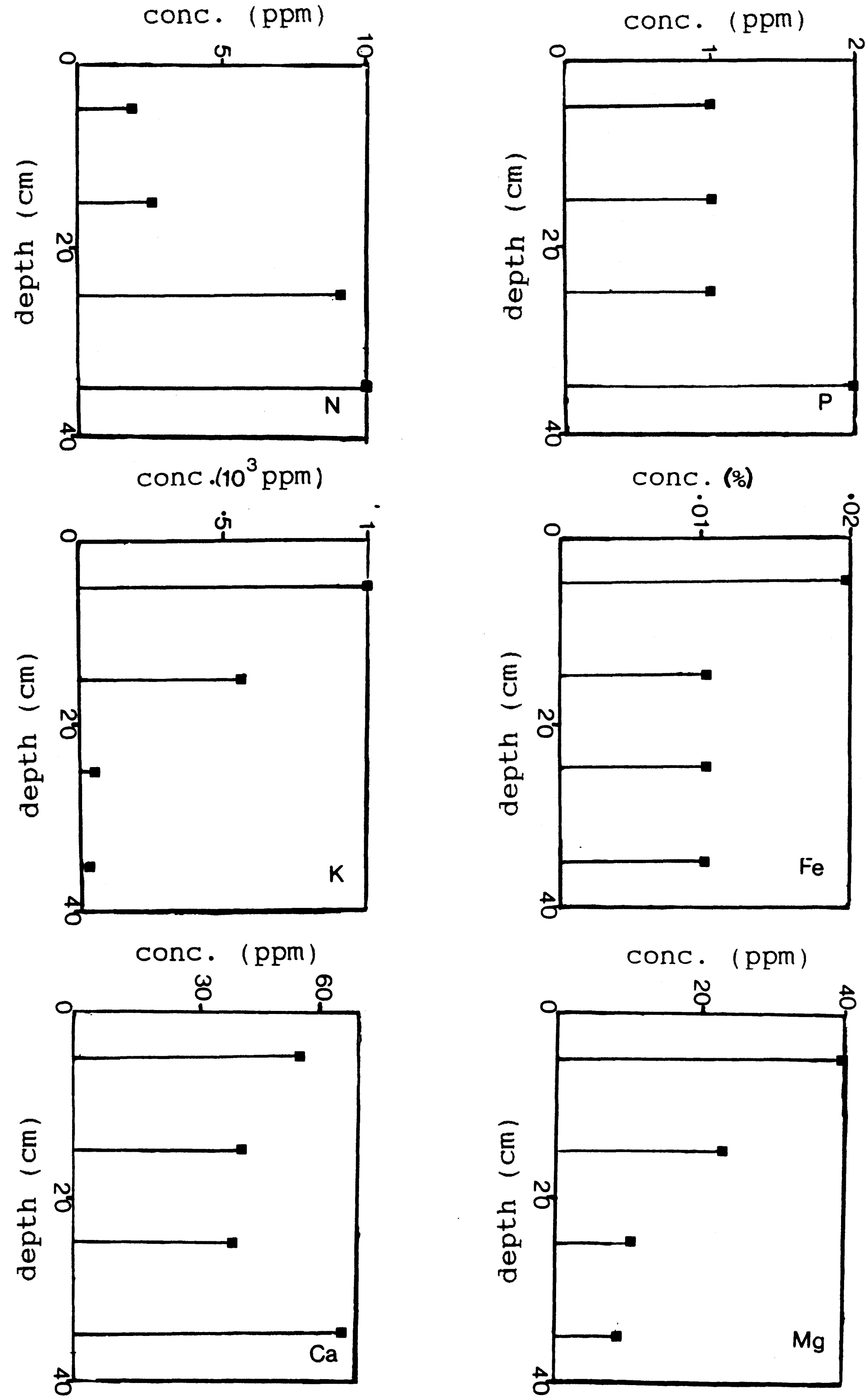

Fig. 4.2a. Concentrations with depth, colluvium.

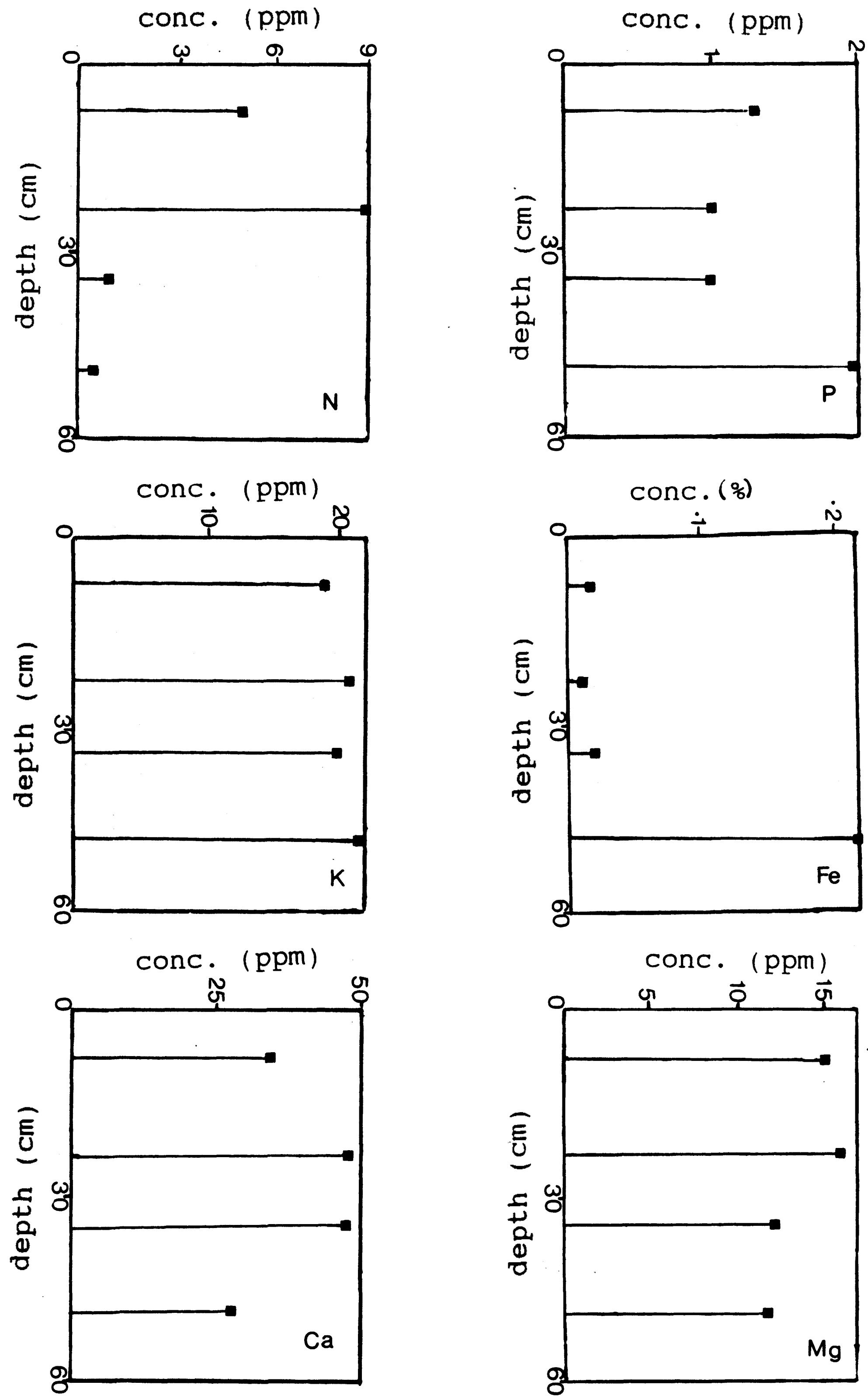

Fig. 4.2b. Concentrations with depth, alluvium.

nitrate-rich compared to the lower 20 cm. This could be due to the nitrate or ammonium conveyed by the runoff and sediment which is deposited on the alluvial plain. In the case of ammonium, nitrification could have occured in the water by the time it reached the floodplain (Gromiec et al., 1983; Wyer,1988). Neither the colluvial fans nor the floodplains showed distinct soil horizons. In recent years check dams have been built at the mouth of the gullies for sediment control. As the lower portions behind the dams are filled out, these reclaimed areas are then planted with fruit trees (Section 3.2.2) and other crops (Section 4.2.2).

4.2.2 Fishponds and agricultural fields

The wetlands are sometimes dredged to form ponds in which carp, prawns and snails are kept for sale in the local markets. Grab samples of sediments from 4 ponds had a texture of clay silt and a dry soil colour of 10 YR 7/4. In order to prevent iron concentration in the pond water from becoming so high as to be toxic to the fish, the ponds are drained and their surfaces limed in rotation (since it is too expensive to do all the ponds at once). Liming the pond mud raises the pH of the pondwaters when the ponds are refilled. At a higher pH iron is less soluble and precipitates out as iron hydroxide (Stumm and Morgan, 1981). The pond waters stay neutral to alkaline because fish discharge pure NH_3 in their waste (which becomes NH_4^+ in water as H^+

ions are taken up) and the pH is given in the Appendix. The nutrient composition of the pond mud is given in Table 4.3. When the pond is drained the following year, the surface mud is removed and used as fertilizer on the farmers' fields.

Cultivated crops include citrus fruits, peanuts, cassava, bananas and a certain medicinal herb known locally as baji (Morinda Officinalis). Mixed planting reduces the danger of loss by spreading the risks over plants of varying susceptibilities to different diseases (FAO,1980a). The citrus fields in particular have a varied agricultural history. There, the original alluvial soil was considered too sandy to retain sufficient moisture and nutrients for that particular crop so topsoil was brought in from the nearby fern-covered slopes and spread over the fields to a thickness of 30 cm. Two years later, pond mud was added as fertilizer to the soil to help the development of the topsoil.

Soil horizons were only vaguely defined. The soil has a texture of loamy sand and a dry soil colour of 5 YR 6/4. The pH of the soil averaged from 4 samples is 4.16. The nutrient composition is given in Fig.4.2ci. Potassium and calcium levels are very high at the surface. The pH of the soil from the citrus fields in the tributary valley is 4.00 and its nutrient composition with depth is given in Fig.4.2cii for comparison with the

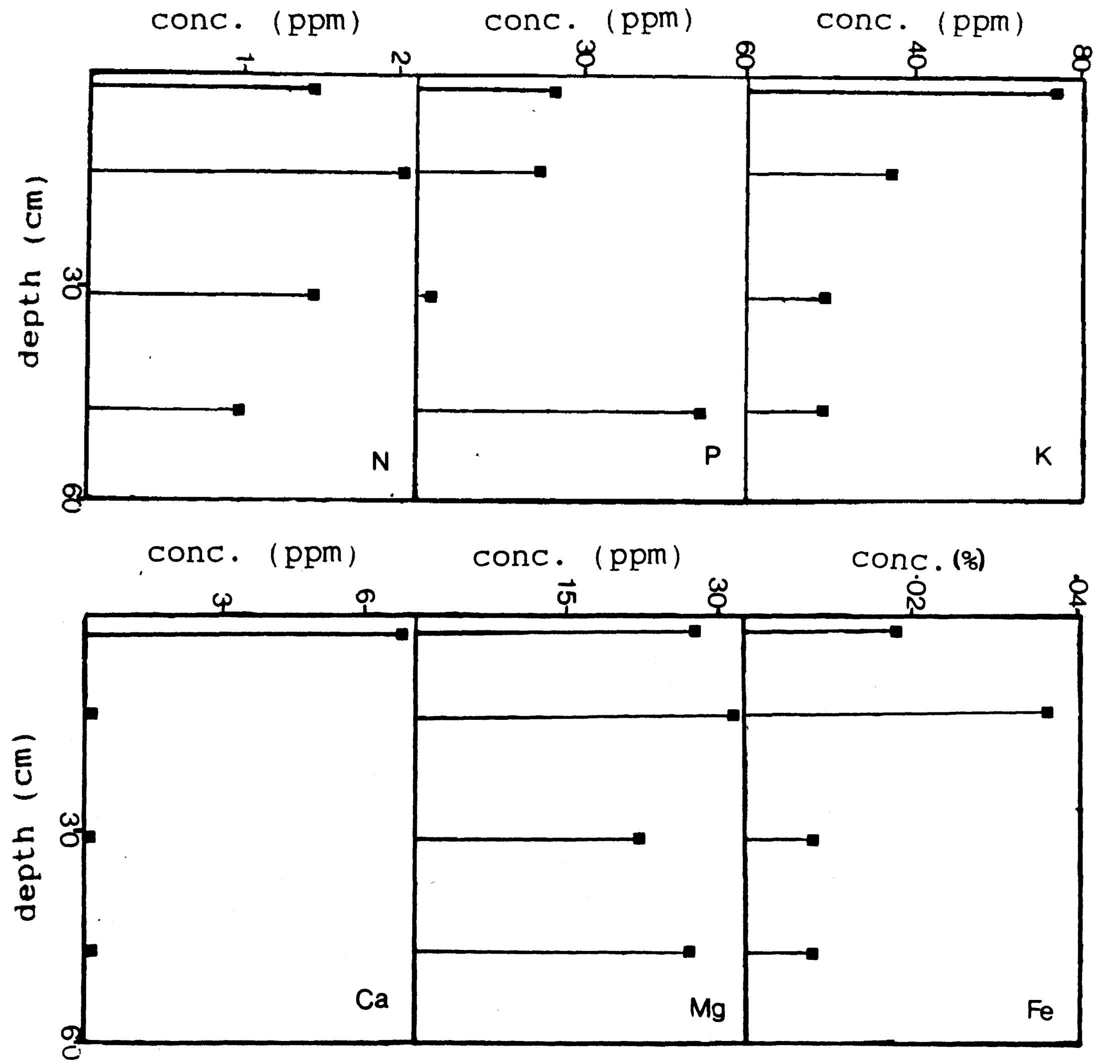

Fig. 4.2ci. Concentrations with depth, citrus field on floodplain.

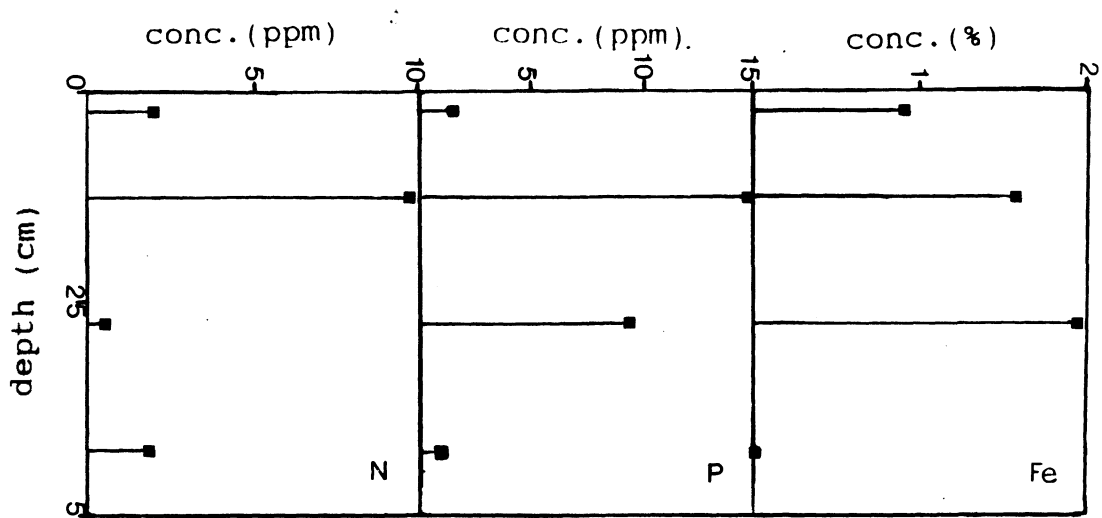

Fig. 4.2cii. Concentrations with depth, citrus field in tributary valley.

citrus fields on the old floodplains. Nitrate levels are much lower in these fields than in the tributary valley fields but phosphate levels are higher.

Although peanuts are cultivated, they are less valued as a commercial crop than they are as a nitrogen fixative. An advantage is that the crop can be harvested within a hundred days of planting, thus, allowing plenty of time for a second crop to be grown and mature during the same year. The soil is a sandy loam, blocky in structure with a Munsell dry soil colour of 10 YR 7/6. The soil appeared poorly drained and the water table occured at a depth of 45 cm on 29 May. Some gleying is evident at this depth. The pH of the soil is 5.38 and the chemical composition is given in Fig.4.2di. The pH of the peanut field soils in the tributary valley is 4.9 and its nutrient composition is given in Fig.4.2dii for comparison.

The nitrogen fixing capacity of the peanut plant can be seen from the high nitrate levels in the soil at the end of the peanut harvest, at which time cassava is planted in the same fields. Cassava is acid tolerant and can be grown in soils of low fertility (FAO,1977; Landon,1984). During dry spells it will go into dormancy rather than die out. The water table was higher, at a depth of 33 cm on 14 July, than when it was observed in May. When planted with cassava, the pH of the soil is lower at 4.52. The chemical composition is given in Fig.4.2e. This field showed higher

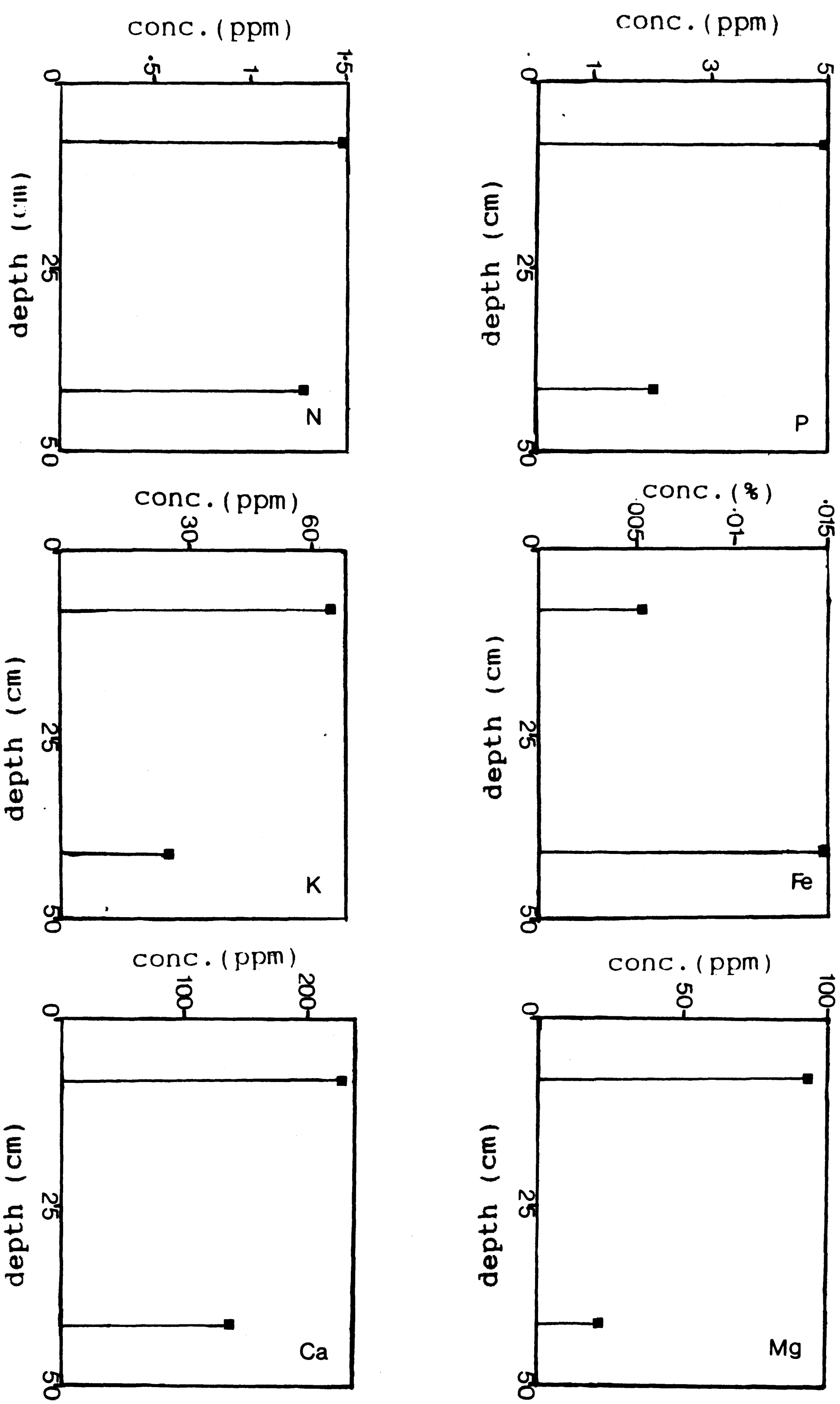

Fig. 4.2di. Concentrations with depth, peanut field on floodplain.

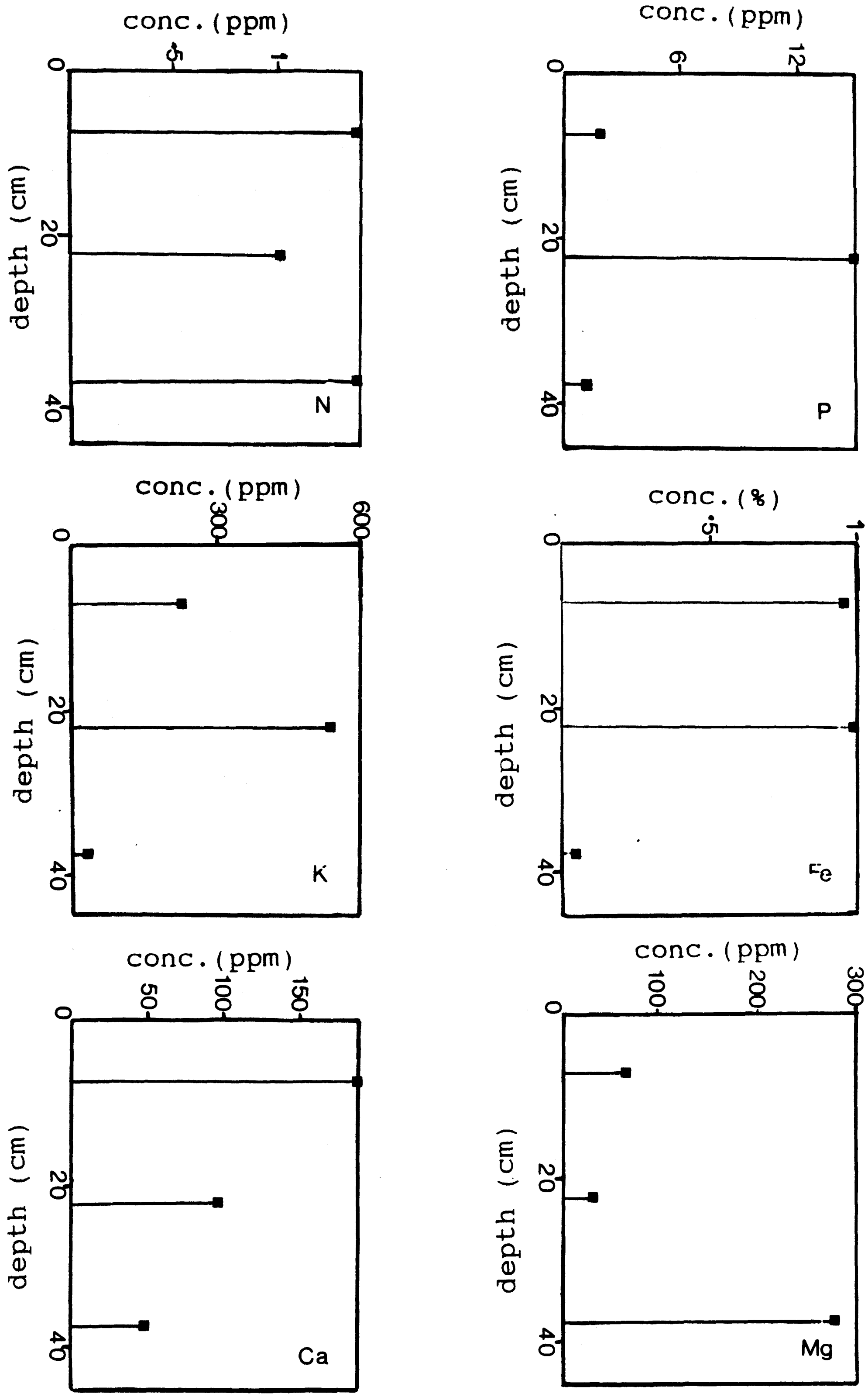

Fig. 4.2dii. Concentrations with depth, peanut field in tributary valley.

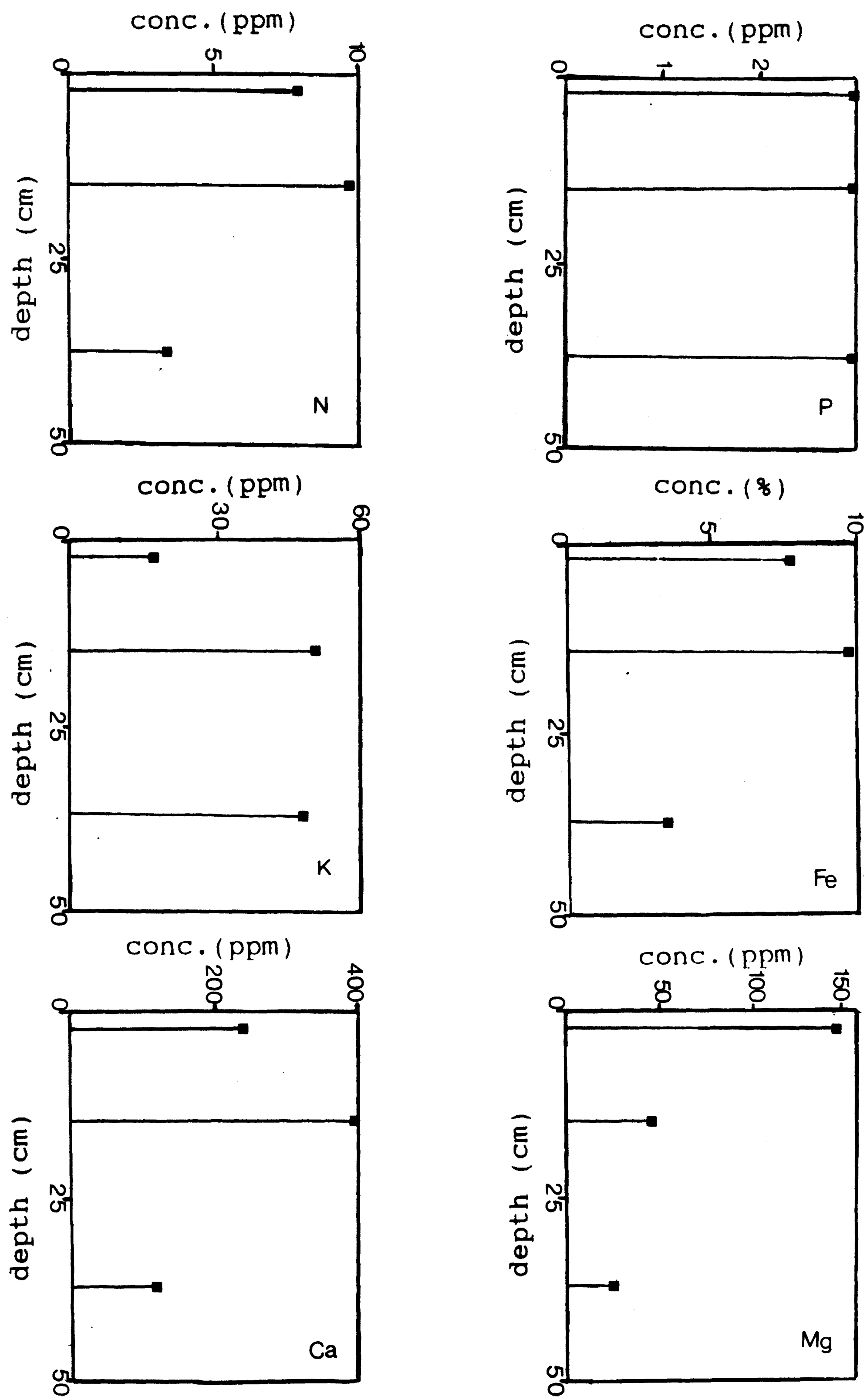

Fig. 4.2e. Concentrations with depth, cassava field.

nitrate concentrations than the other fields. Concentrations are higher in the upper 25 cm of the profile than the lower 25 cm.

Bananas are grown on sandy soil unaltered by the addition of topsoil. The soil is a loamy sand with a Munsell dry soil colour of 5 YR 6/6, a blocky structure and pH is 4.5. The phosphate concentration is higher in the top 18 cm than below. Phosphate is not a very mobile ion and ions entering the soil through rainfall will remain close to the surface rather than leaching deeper into the soil (Frere et al.,1980). Potassium and magnesium concentrations are higher deeper down inthe soil (Fig.4.2f).

At the field where the baji (**Morinda Officinalis**) seedlings were nurtured, O horizon is approximately 8 cm in depth, containing plenty of undecomposed roots and twigs. The soil is a silty clay loam with some gleying and a dry soil colour of 2.5 yr 6/4. Some fine roots are evident in the top 20 cm. The silt content increased with depth. The pH of the soil is 4.52. The nutrient composition is given in Fig.4.2g. Nitrate was much higher in the O2 horizon compared to the horizons below. The B2 horizon has more extractable iron than the upper horizon, probably because of leaching and illuviation.

4.2 Discussion

4.2.1 Elemental trends

In terms of the 6 nutrients analyzed, the level of

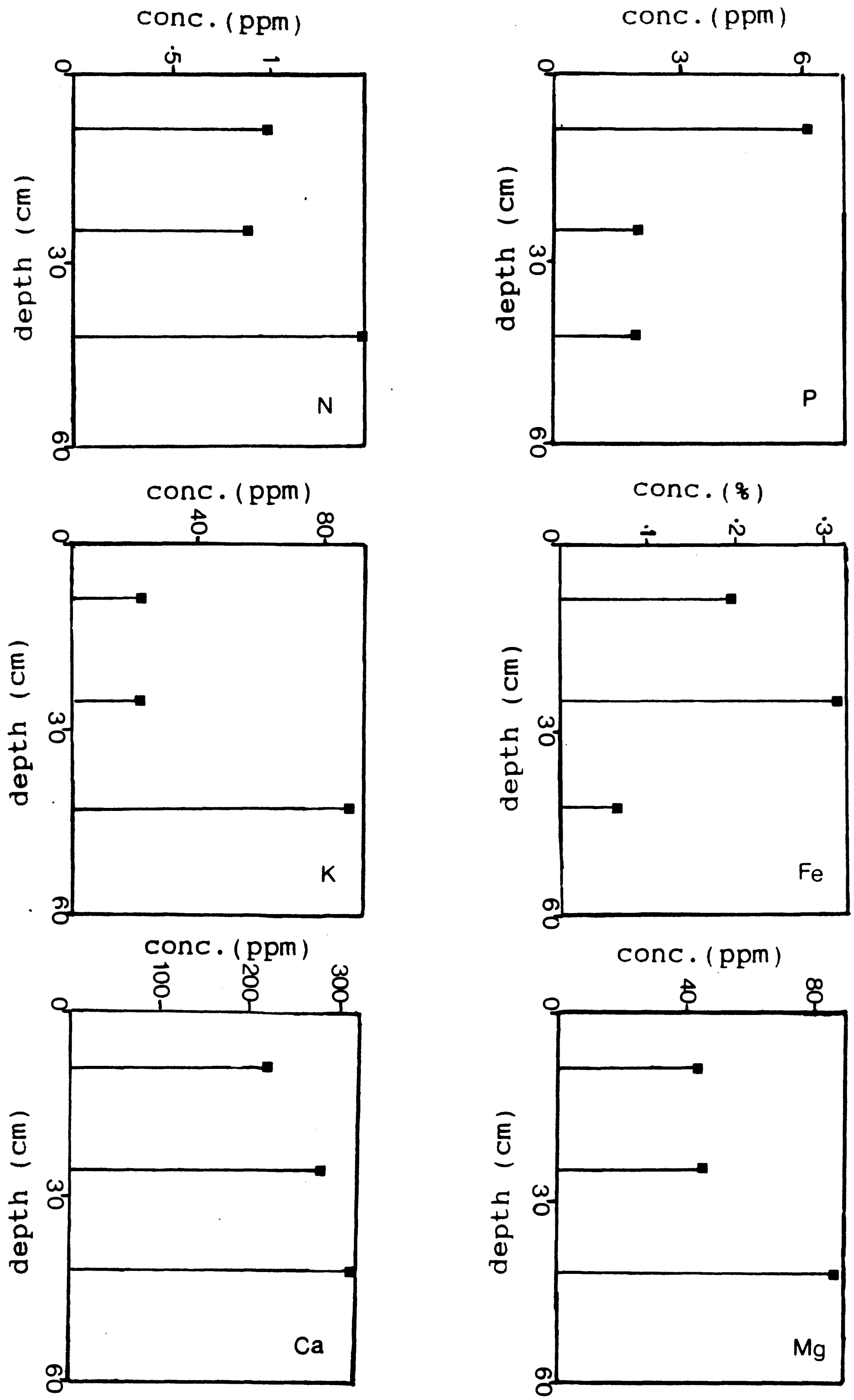

Fig. 4.2f. Concentrations with depth, banana field.

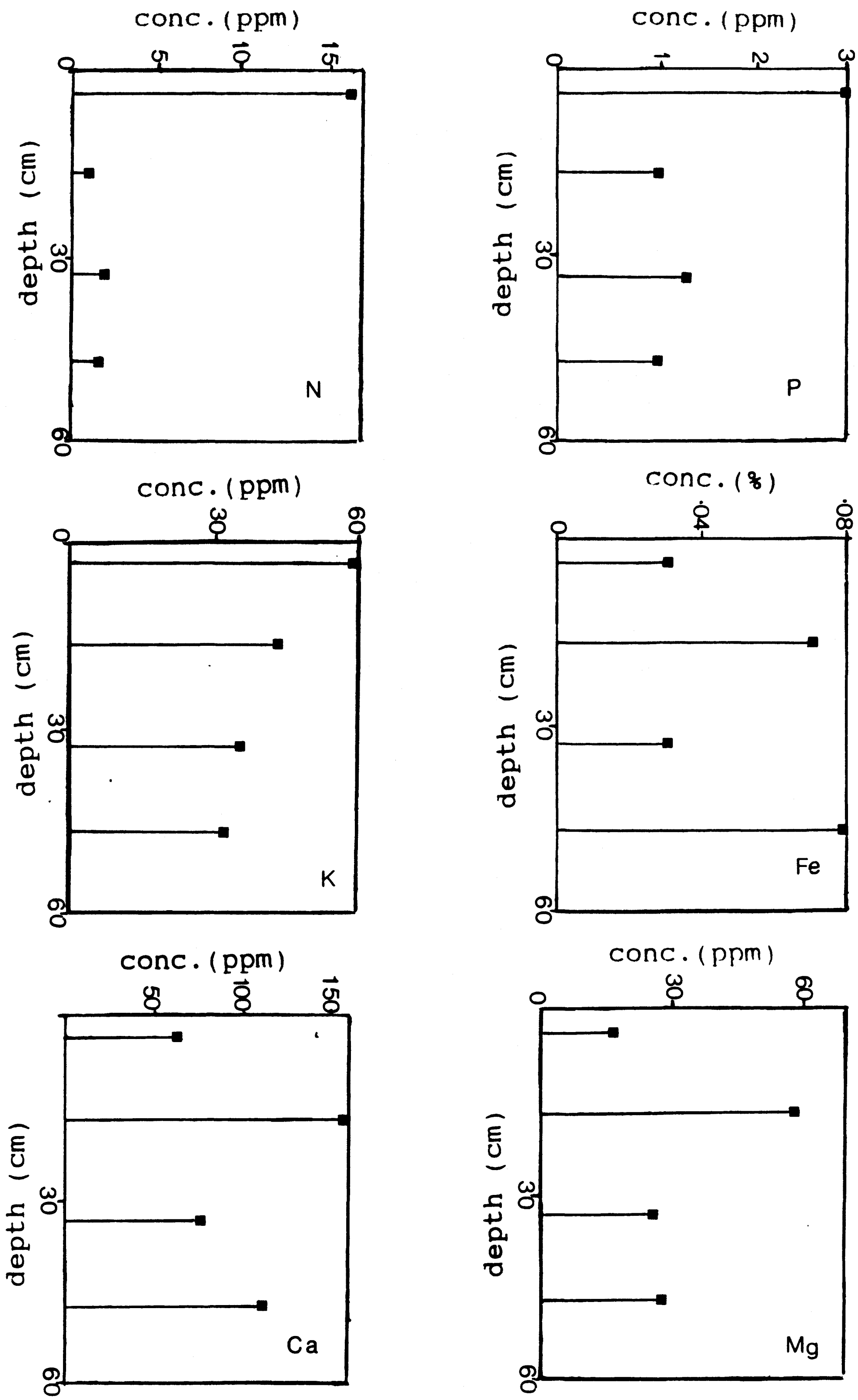

Fig. 4.2g. Concentrations with depth, baji field.

available iron was higher than the levels of the other nutrients at a factor of a hundred to a thousand times. Since the soils are very weathered it was not surprising to find extremely high levels of iron. Only total aluminum levels were analyzed, but because of the very acidic environment it can be inferred that free aluminum would also be high. The high concentration of soluble iron and aluminum would be toxic for the plants, affecting crop productivity (Foth, 1984). The hydrolysis of these transitional elements also means that the H+ concentration is constantly increasing to depress the pH of the soils (Section 1.3.3). This suppresses plant uptake of nutrients and inhibits cell division and translocation of nutrients within the plant (Buckman and Brady,1968; FAO,1986). The low pH also affects the availability of the other nutrients (to be discussed later). In Southern Ontario, for example, the minimum pH at which it is considered feasible to grow crops is 4.80 (Wright, 1988) and the recommended pH for crop cultivation on tropical soils is 5.5 (FAO,1984).

Levels of nitrate-nitrogen in the soil profiles ranged from quite high (cassava) to low but, as mentioned in section 3.3, it is possible that ammonium is the main form of mineral nitrogen in highly acidic soils (Poovarodom et al, 1988). Under such conditions nitrifying bacteria is inhibited and inorganic nitrogen stagnates at the ammonium stage. Since plants absorb both nitrate and ammonium ions quite easily, the consequence of ammonium being the dominant species is that this study offers only a partial picture of the mineral nitrogen available to the plant. Although nitrogen availability is influenced by organic matter content, soil moisture and temperature (Buckman and Brady,1968), the last two factors are not critical at Shenchong basin because of the hot,wet climate. The soils have low organic content (Luk et al.,1987) but it is difficult to determine losses through leaching as infiltration rates for different fields vary (figs.4.1a,b). Moreover, there is no standard test to date to determine plant nitrogen requirements from soil tests alone (Greenwood, 1986 and Ontario Ministry of Food and Agriculture, 1988). Only field experiments involving the plants will indicate their response to fertilizer which would allow extrapolations to possible crop yield. This is especially true as some crops are bred to respond to fertilizers and will require a higher degree of soil fertility than the indigenous crop type which is adapted to poor soil conditions (FAO,1980b).

Available phosphorus was very low in these soils since the parent rock provides little of this element. Furthermore, these soils have had their biomass removed for centuries without the benefit of fertilizer to replace losses. The high concentration of free aluminum and iron also means that the little phosphate in the soil is complexed into insoluble aluminum and iron compounds (FAO,1980b). Vegetation may affect the level of available phosphate in the soil because as plants absorb phosphate and remove it from the soil water solution the equilibrium state is disturbed and more phosphate becomes soluble (Barber,1984; FAO,1984).

Calcium levels were very low as is expected from an area of acidic granitic bedrock. At this site the highest cations are iron and probably aluminum. Compared to soils from other tropical regions (Table 4.1), these soils have very little calcium. Magnesium levels were also low as befits highly weathered materials from which the acid soluble magnesium compounds would have long been leached (Chapman, 1966). At some sites potassium levels seem on par with the other soils because this element is derived from biotite granite which contains more potassium than magnesium. In fact, some of the loss is compensated by the release of K^+ from minerals (FAO,1984) and the storage of potassium in plants (Section 1.2). This observation is discussed further in the next section.

4.2.2 Spatial trends

The pH levels of soils in Shenchong Basin are low (Fig.4.4a). Levels of available iron are higher in the upland soils (the bare slope being the exception) than the

Table 4.1 Nutrient concentrations in soils from different tropical regions and Southern Ontario.

REGION	AVAILABLE PHOSPHORUS (ppm)	POTASSIUM (ppm)	EXTRACTABLE CALCIUM (ppm)	MAGNESIUM (ppm)
MALAWI (LANDON, 1984)		78 156 312		
TROPICAL SOILS (LANDON, 1984)	4 7			30 60
QUEENSLAND (NAT. ACAD. SCIENCES, 1972)		39 70		
REP. OF CONGO (NAS,1972)		26		
MALAYSIA (NAS,1972)		60--117		
IVORY COAST (NAS,1972)		39 156		
NEW GUINEA (EDWARDS AND GRUBB, 1985)		207 382 208 370	1844 2786 1483 6208	302 588 280 985
PANAMA (GOLLEY ET AL. 1975)	1.7 9.1 14.0 0.7	606 650 850 80	7880 2420 4700 7500	1144 70 1620 1330
COSTA RICA (GOLLEY ET AL.,1975)	1.1	82	1534	600

Table 4.1 cont.

COSTA RICA (MARRS ET AL.,1988)	2.2	78	241	36
JAMAICA (TANNER, 1977)	ND	1242	462	313
HONG KONG (GRANT,1960)				
KAM TIN	.6	33	887	154
TAI HONG WAI	5.0	44	335	64
PAK WAI TSUEN	2.0	21	324	88
PING CHE	1.2	34	255	33
TAI MO SHAN (POORLY DRAINED)	1.7	30	115	37
TAI MO SHAN (WELL DRAINED)	1.2	7	42	16.6
ONTARIO, (GAGNON, 1988)	2-7	50-150	2,000-10,000	25-400

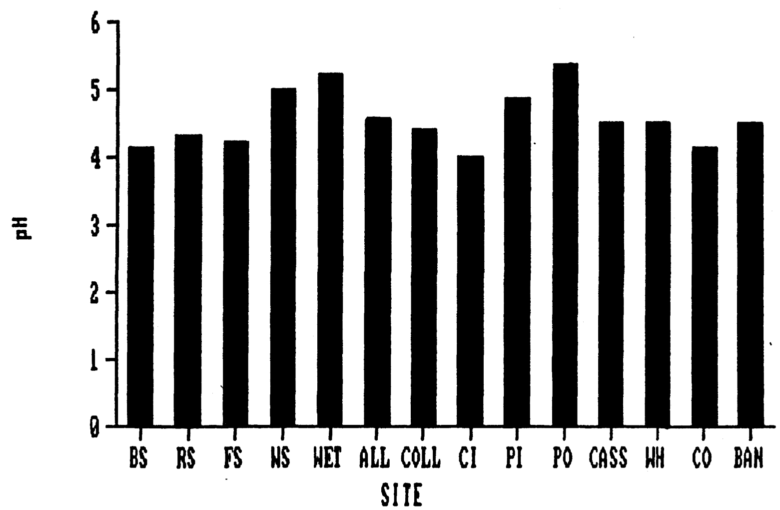

Fig. 4.3a. pH of Shenchong soils

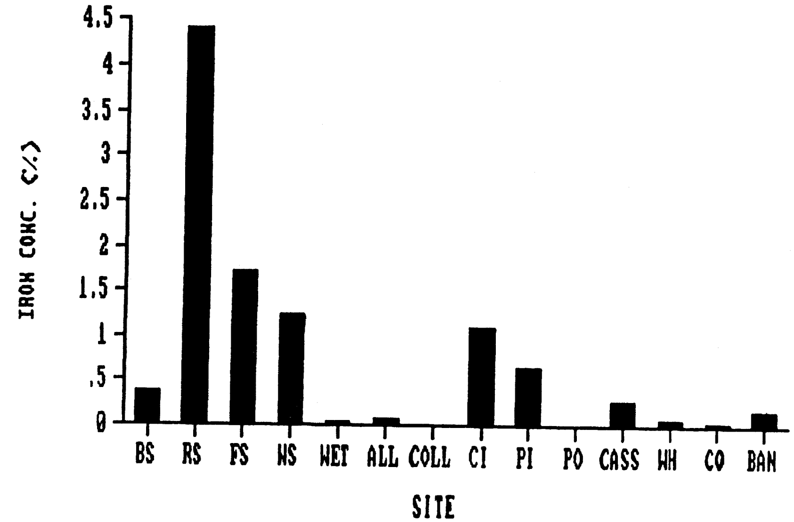

Fig. 4.3b. Iron concentrations in Shenchong soils

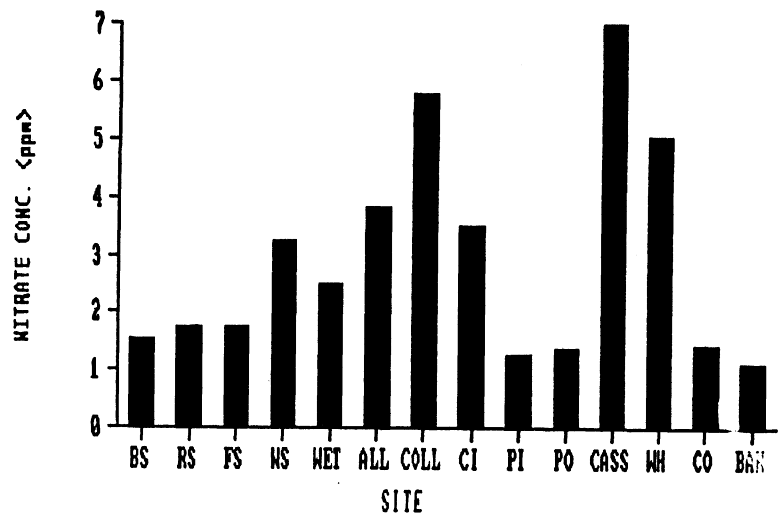

Fig. 4.3c. Nitrate concentrations in Shenchong soils.

LEGEND

BS	Bare slope
RS	Revegetated slope
FS	Fern slope
WS	Wooded slope
WET	Wetland
ALL	Alluvium
COLL	Colluvium
CI	Citrus field in tributary valley
PI	Peanut field in tributary valley
PO	Peanut field on former floodplain
CASS	Cassava field
WH	Baji field
CO	Citrus field on former floodplain
BAN	Banana field

lowland soils by a factor of 10 to 100 irrespective of whether the lowlands are cultivated or not. Since the lowlands consist of sandier soil than the uplands, this difference could be attributed to iron affinity for clay particles. The next highest levels are in the citrus and peanut fields of the tributary valley, followed by the cassava and banana fields, then the unvegetated alluvial fans and then the citrus and baji fields on the floodplain, the wetland, and the colluvium and, finally, the peanut fields of the old floodplain (Fig.4.3b). Another point is that while nutrient levels are similar for the peanut and cassava fields, they are very different in terms of available iron. This could be because the peanuts were planted and harvested before the wet season while cassava was planted after the arrival of the rains that raised the water table; and the soluble iron in the groundwater increased the concentration of iron in the soil solution (Foth,1984).

Nitrate showed no conspicuous spatial trend, but as mentioned in Section 4.3.1 the cassava field had the highest level of nitrate followed by the the colluvial fans, then the baji field and then the alluvial plains. The remaining sites in a descending order of nitrate levels were the citrus fields in the tributary valley, the forested slope, the wetlands, the reforested, fern and bare slopes and then the floodplain citrus and peanut fields, the peanut fields in the tributary valley, and lastly, the banana field (Fig.4.3c). The levels in the colluvial fans and the alluvial plains could be explained by surface runoff and stream discharge which deposited organic matter on the surface of the fans and plains. Wyer (1988) suggested that nitrification rates are higher when the suspended sediment transported has a particle size greater than that of the nitrifying bacteria. Furthermore, Kinjo and Pratt (1971) have observed that nitrate is adsorbed on to aluminosilicates (sand grains) since there is less competition for adsorption sites with phosphates (phosphates have a greater affinity for clay particles).

The high level of nitrate at the forested site is because the nitrogen cycle in a forest is in equilibrium since nitrogen taken up by plants is returned to the soils in the form of leaf litter (Tivy,1987). This same explanation could be applied to the fern and reforested slopes, although levels would be lower here because the system has been in place for a shorter period. The relatively low level of nitrate in the bare slope is the result of topsoil removal by severe erosion. The low levels of nitrate in the cultivated fields can be explained by the crops absorbing nitrogen but not returning as much to the soil since the crops are harvested rather than being left to decompose on the field as in the case of the natural vegetated sites. The exceptions are the floodplain peanut and cassava fields which have been discussed in Section 4.2.2. It is difficult to explain the high level in the baji field and the low level in the peanut fields. It is possible in the case of the baji seedling field that the plant itself has some nitrogen fixing capability that has not yet been documented in literature. In the case of the tributary valley peanut field and the banana field, leaching was probably excessive in the sandy soil (Section 4.4). The low level in the outer peanut field could have been due to losses to the groundwater before the plants had sufficient time to build up a surplus of nitrate.

Cultivation is the factor determining calcium levels in the soil because of the liming of the fields. The extremely high levels in the outer citrus fields can only be explained by the presence of lime. Perhaps too much lime was collected with this sample to make the result so high and possibly not very representative of the general condition. Soils from the peanut fields have a higher pH than the other fields, but it is not known if the peanut fields were limed to a greater degree than the others. Peanuts require a large amount of calcium because calcium is not a mobile ion and if it does not reach the fruiting organ, poor kernel development results (FAO,1984). The relatively silty soil of the peanut field is also more likely to retain a higher pH than the sandier soils for a longer period after liming (Doane,1987). There has been no previous evidence that peanut cultivation increases the pH of the soils. Moreover, pond mud is used as a fertilizer and since the ponds are limed this will also contribute to the higher calcium content. In fact, the soils on the slopes are generally more deficient in calcium than the relatively unvegetated alluvial and colluvial lowland soils (Fig.4.3d).

It is difficult to explain the predominance of potassium in the colluvial soils. Foth (1984) observed that high potassium levels in alluvial soils is due to its release by flooding but this does not explain why potassium is high in the colluvium instead of the alluvium. The high potassium content in the colluvium is probably related to the high potassium levels observed in the gully sediments (section 3.4) which is the source of the colluvium. Elsewhere potassium levels can be linked to vegetation. Although potassium in soil originated from the parent rock, vegetation cycling could have some bearing because most of the fields have similar levels of potassium as each other, while the bare slopes are similar to the sparsely vegetated slopes (Fig.4.3e). The high levels in the fields of the tributary valley can be explained by the addition of

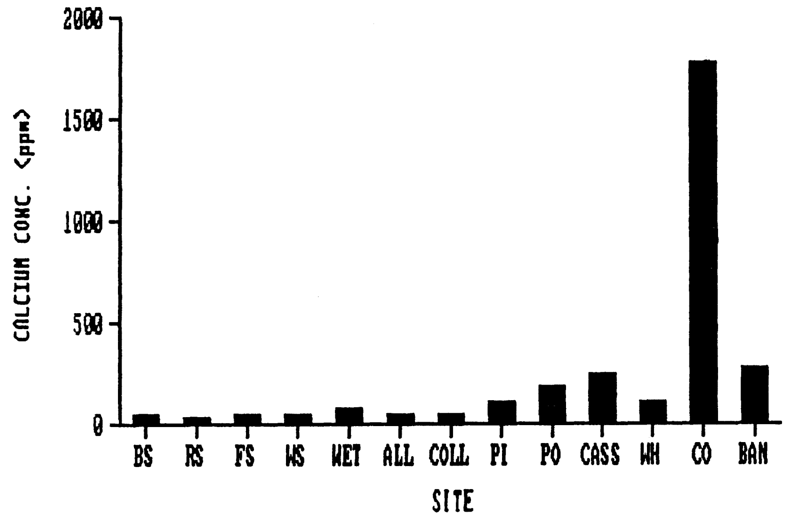

Fig. 4.3d. Calcium concentrations in Shenchong soils.

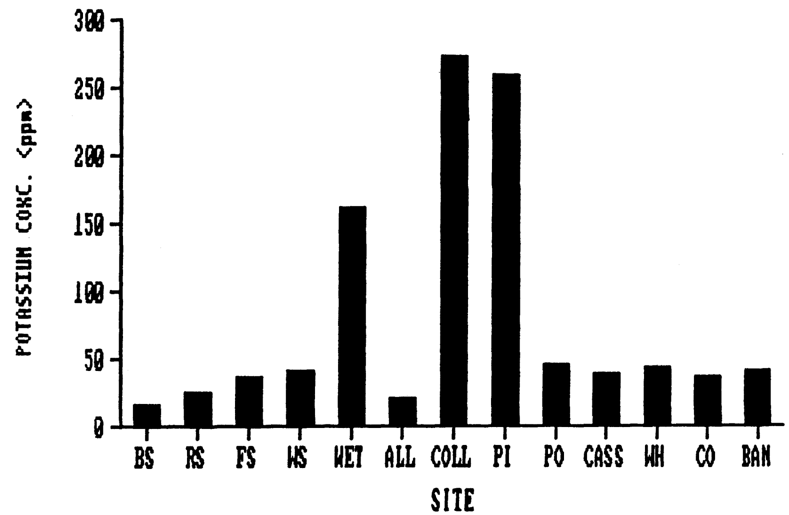

Fig. 4.3e. Potassium concentrations in Shenchong soils.

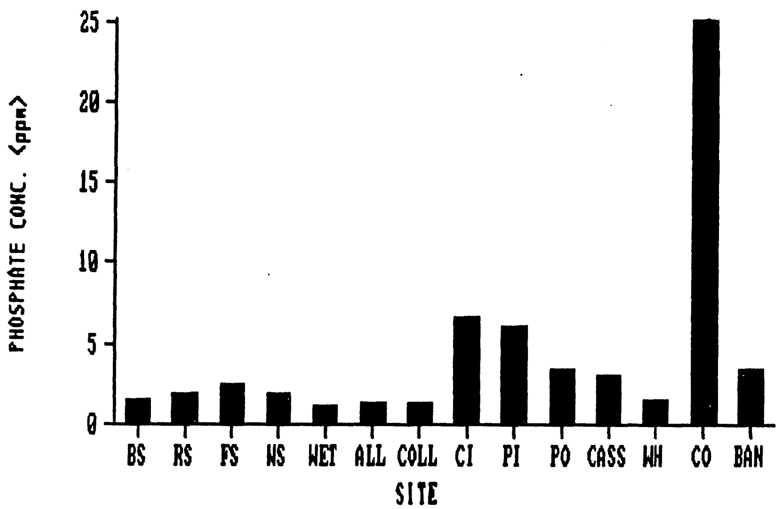

Fig. 4.3f. Phosphorus concentrations in Shenchong soils.

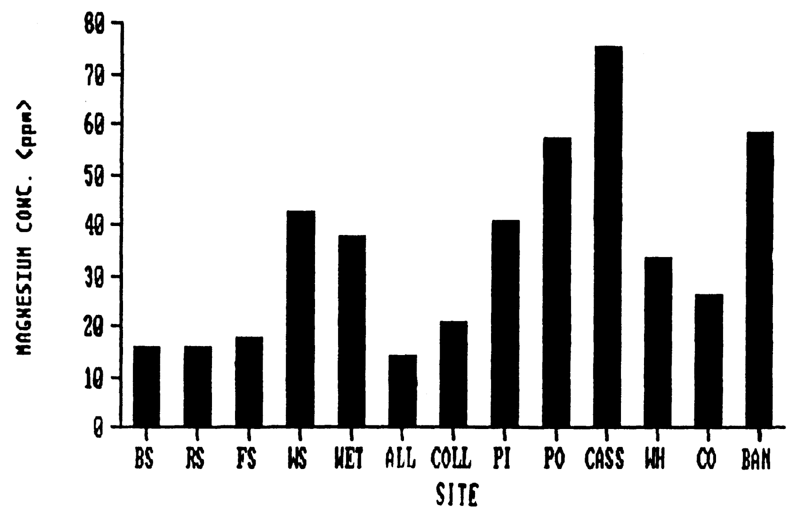

Fig. 4.3g. Magnesium concentrations in Shenchong soils.

potassium-rich burnt grass and the high level in the wetlands can be explained by decomposing vegetation. Foth (1984) and Puckett (1987) mentioned that potassium does not form an integrated component in the plant tissue, and therefore can be easily washed off the plants during a storm.

Agricultural fields showed higher levels of available phosphorus, probably due to the addition of organic fertilizers such as pond mud, burnt grass and abatoir refuse. Next are the soils of the vegetated slopes; then the bare slopes, followed by the alluvial plains, then the colluvial fans and lastly, the wetlands (Fig.4.4f). Although available phosphorus in the soil is quickly complexed by iron and aluminum, the kinetics of phosphorus release are governed by the compound formed. The more soluble raw oxides of aluminum and iron change into the highly insoluble forms of strengite and veriscite over time (Foth,1984). The relatively higher levels in the peanut and cassava fields in the main valley can be explained by the higher pH, but this reason cannot be applied to the outer citrus fields. The presence of vegetation also has some influence because, as was mentioned before, as vegetation absorbs soluble phosphorus from the soil solution more phosphorus will go into solution to replace that which has been removed (FAO,1984). This would explain why the bare slopes, colluvial fans and alluvial plains are the most deficient in phosphorus.

Magnesium is derived mainly from biotite granite, but there is little magnesium remaining in the severely weathered soils. Magnesium levels did not show a well defined spatial trend. It appears that the cultivated fields have more magnesium than the slopes and the colluvial fans, with the alluvial plains having still less (Fig.4.3g). This could be due to the presence of magnesium in the dolomite which is used to lime the fields. The one exception in this trend is the soil from the wooded slope which has relatively higher magnesium than the other slopes. This is because the nutrient cycle is in equilibrium and nutrients are not removed from the forest ecosystem by erosion or by cultivation (Section 1.3.3).

It must be stressed that only broad generalisations should be made from these interspatial differences. Since the original samples from the same sites had to be combined, it was not possible to obtain a standard error associated with the analytical results. Therefore, small variations could be explained by statistical and sampling errors.

4.3 Fertilizers and Productivity

The soils of Shenchong basin are not very fertile when compared to fertility indices for phosphorus, potassium and magnesium (Table 4.2) taken from Mengel and Kirkby (1983). Under this system of evaluation, fertilizer

Table 4.2 Indices of P, K and Mg in relation to available soil nutrients (Mengel and Kirkby, 1979).

Index	P	K (ppm)	Mg	Interpretation
0	0-9	0-60	0-25	Deficiency in arable crops
1	10-15	61-120	26-50	Possible deficiency in susceptible crops
2	16-25	121-240	51-100	
3	26-45	245-400	101-175	
8	201-280	2410-3600	1010-1500	Excessively high levels

Table 4.3 Nutrient content in organic fertilizers used in Shenchong Basin.

Fertilizer	N (ppm)	P (ppm)	K (ppm)	Mg (ppm)	Ca (ppm)	Fe (%)
Pond mud	1.0	3.0	74.6	120.1	40.0	2.72
Abatoir refuse	3.2	1.5	1060	102.3	296.0	.02
Burnt grass	7.5	21.0	1240	179	440	.53

Table 4.4 Comparison of Shenchong Basin crop yields with typical crop yields from other tropical areas.

Crop	Shenchong Basin (tons/ha)	Tropical area (tons/ha)
Banana	8-10	15-25
Cassava		15-25
Citrus	2-3	8-15
Peanut		1-2

is definitely needed to make up the phosphorus and magnesium deficit. Intensive cropping (these fields are rarely left fallow) may necessitate the application of potassium fertilizer but this is debatable as levels of free potassium in the soil are dictated by the potassium requirements of the vegetation, and as non-exchangeable potassium can convert to available potassium after potassium is removed from the soil solution pool (Walsh and Beaton, 1974). However, Oliviera et al. (1971) observed that although non-exchangeable potassium can be converted to exchangeable potassium, this process is slow and does not keep up with the plant requirements. For tropical acid soils, lime and phosphorus fertilizer should be an immediate priority followed later by nitrogen and potassium fertilizers (FAO,1986).

Since industrial fertilizer is expensive, organic fertilizer is more commonly used and often produced on the farm itself. Ammonium nitrate and ammonium sulphate, the common commercial nitrogen fertilizers used, have the disadvantage of lowering the pH of the already acidic soils (FAO,1974). Organic fertilizers have the advantages of being cheap, relatively non-toxic and increasing organic matter content but they are low in nutrients and mineralize slowly. In an area of heavy seasonal rainfall such as this, slow nutrient release is an advantage as losses through leaching and runoff are minimized. While immediate gains from organic fertilizers do not compare favourably with industrial fertilizers, the long term benefits of soil improvement and conservation as well as less pollution make them an attractive choice (FAO,1982). The nutrient analysis for the fertilizers used are given in Table 4.3. It was not possible to obtain a sample of the chemical fertilizer used during the field season, but the quantity used is very limited.

The burnt grass cuttings are by far the most nutrient-rich of the natural fertilizers. Grass tilled into the soil in the unburnt state will take a long time to decompose and for the nitrogen to mineralize because the soil is very acidic. Thus, the grass cuttings had to be burnt to release the nutrients. The grass cuttings are easy to obtain but, unfortunately, their nutrients are easily lost through leaching, as seen in the groundwater from the well adjacent to the fields where burnt grass was applied (Table 3.4). Losses could also occur through volatilization and ash particles blown away during burning. Abatoir refuse is rich in potassium. In addition, abatoir refuse is low in iron, which is already present in toxic quantities, so that this would be an advantage over the other fertilizers. It is important to realize that nutrients work together and must be balanced with respect to each other for optimum productivity (FAO,1970).

The quality of crop yields depends on the inherited genetic composition of the crop and environmental factors. The former determines the inherent quality while the latter affects the potential realization (FAO,1984). Table 4.4 shows the productivity of the crops; and for the peanuts, citrus, bananas and cassava, values from literature are given as a comparison. Peanuts and citrus fruit yields are low and the cassava crop is susceptible to root disease. This could be attributed to a deficiency in phosphate which has been known to cause root diseases in some root plants (OMAF,1988). In addition, the nitrogen fixing capability of the peanut plant is impaired when the pH falls below 5 (OMAF, 1988). Even the benefit of the higher nitrogen levels in the soil is reduced because the low level of phosphorus inhibits the uptake of nitrogen. Mutant strains do develop a tolerance to aluminum but this is at the expense of the nodules for nitrogen fixation (FAO,1982). Additionally, rhizobia do not grow well anaerobically and may be inhibited in the poorly drained outer peanut fields (FAO,1982). While the present plant types can be replaced by higher yielding varieties, the latter also require greater modification to current conditions than do the native varieties (FAO,1980b). The relevance of these results to the basin's agriculture and recommendations for improving crop yield will be dicussed in the last chapter.

CHAPTER 5

SUMMARY, RECOMMENDATIONS AND CONCLUSION

5.1 Summary

This study has examined the nutrient status of the soils of Shenchong Basin in Deqing County in Guangdong province, China. Nutrient input from rainwater and subsequent losses through runoff from the upland slopes were analyzed. Moreover, nutrient levels of upland soils were compared to lowland soils, and those of vegetated surfaces were measured against unvegetated surfaces. Lastly, different kinds of organic fertilizers used by the farmers were analysed in order to determine their relative effectiveness. Nutrients in the soil are derived from various sources: the atmosphere, microorganisms and the parent rock. Nutrient input through rainfall is generally low, and the major input is from the weathered materials of the parent rock. Surface runoff response was rapid from bare slopes, rills and gullies, but slight from vegetated slopes and rills. Nitrate and orthophosphate concentrations in runoff were generally low. Given that the ratio of ammonium to nitrate concentration was in the neighbourhood of 10:1, it is likely that the dominant form of inorganic nitrogen present was ammonium. In gully G9C there was a reversal in the ammonium to nitrate ratio over the course of a few storms. This could be due to the ammonium in the soil being flushed out by the first few storms, after which the concentrations of the species are more a reflection of the rainwater content. Potassium was the highest of the nutrient concentrations showing a spatial trend that seemed related to vegetation. Calcium and iron concentrations were moderate and of a similar magnitude, although the calcium was probably attributable to inadvertant contamination from the concrete boundaries.

Iron and aluminum levels were very high in the soils. The main factor influencing the level of available iron in the soils appears to be whether the soils are from the uplands or lowlands. Lowland soils generally contain less clay than upland soils and aluminum and iron adsorb on to clay particles. Phosphorus and calcium levels were low and the higher levels present in the fields were probably a function of the lime added by the farmers. Magnesium levels were low to moderate, being slightly higher in the cultivated fields, also probably due to the lime. Potassium levels were quite high and seemed to be related to vegetation, with the vegetated soils having higher levels. Nitrate levels were generally low and no specific spatial trend was evident. Soil pH was low, ranging from 4.2 to 5.4. Under such acidic conditions plant nutrient uptake is suppressed as is bacterial activity favorable to nutrient conversion and fixation. Furthermore, a low pH increases the solubility of iron and aluminum and these ions are toxic to plants. High iron and aluminum solubility also reduces phosphate availability, which is suspected of causing heart rot in tubers.

In comparing the three fertilizers presently in use (Section 4.4), the burnt grass contributed the highest levels of available nutrients per unit weight used. However, nutrients released from the burnt grass are the most susceptible to leaching. Although most of the fertilizers currently in use are organic in nature, extensive use of industrial fertilizers might become necessary as the evolving Chinese economy puts pressure on the farms for higher yields. Two of the common nitrogen fertilizers used, ammonium sulphate and ammonium nitrate, both increase the acidity of the soils. Moreover, phosphorus in fertilizer is quickly complexed by the free iron and aluminum, reducing its availability to the crops.

5.2 Recommendations

Suggestions in previous FAO studies (1978, 1980a, 1984, 1986) in South America, Southeast and South Asia can be applied here with some modifications. Some of these alternatives, such as multiple cropping, crop rotation and the use of organic fertilizer, are already in place. The goal for agriculture at Shenchong basin should be optimal yields rather than maximum yields. Optimal yield being defined as the highest possible yield for the most sustainable economic investment with the least environmental damage.

Doane (1987) mentions that liming is often seen as less important than fertilizer addition. In striving to improve crop yields in Shenchong basin, the most significant task at hand is to reduce the high soil acidity and establish the optimum conditions for the addition of fertilizer. A pH of 5.5 has been recommended by an FAO study in 1984 as the optimum value for acid tropical soils. If possible, dolomite should be used as it provides both calcium and magnesium while raising the pH. This should be applied to the top 15 cm of the soil. Organic fertilizers should continue to be used whenever possible rather than industrial fertilizers which are expensive to purchase and transport. Furthermore, fertilizer should be applied at intervals rather than all at once, to reduce losses through leaching and runoff.

Aside from fertilizers, bacterial innoculations and legumes and non-leguminous plants (e.g Rhizobia Japonicum) can be used to fix nitrogen in the soil. Blue-green algae can be used in rice paddies and fishponds to accomplish the same task (FAO,1982).

Plants with a tolerance of, or preference for, high acidity (such as sugarcane and pineapple) could be grown. While cassava can be grown on poor soils (FAO,1977), it is also easily perishable and hence subject to loss where processing facilities are not locally available (Charleton, 1987). In this sense, local authorities could help by encouraging the building of processing plants and improving transportation facilities. Reforestation can form part of an integrated land use policy incorporating slope protection with productivity. However, the current species grown, Pinus Massoniana, increases the soil acidity and is being replaced elsewhere in China with other species (FAO,1980). In Shenchong Basin, as in the rest of Deqing, the resin obtained from the pine trees is an important source of income, and replacing this species will meet with objections. However, as increasing demands for more and better food supplies puts pressure on the farmers to cultivate the upland areas, planning for long-term goals should be considered. The use of rapid-growing cover crops should also be considered to reclaim bare slopes to conserve nutrients and soil.

5.3 Conclusion

In the third world, agricultural systems are implicitly tied into social, economic and cultural factors. Charleton (1987) remarked that ecological sustainabilty is often pitched against social sustainabilty. A range of approaches must be adopted for the most efficient utilization of resources in Shenchong Basin. This will include husbanding of current resources and introduction of low-cost modifications which take into account the social and economic framework of the area. Indeed, future work in the weathered granitic terrain of South China should focus on a comprehensive solution to the nutrient problem currently confronting the region.

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APPENDIX

NUTRIENT CONCENTRATIONS IN RUNOFF

JULY 22, 1987.

LOCATION	TIME	AMMONIUM	NITRATE	PHOSPHATE	TIME	CALCIUM	IRON	POTASSIUM
SB1	17	0	0		17	0	0	0
	17.55	.56	.175		17.08	2.405	2.364	2.98
	17.66	.012	.02		17.25	1.921	.486	3.28
	17.83	.445	.02		17.83	2.371	.12	3.04
	18.88	.48	.08		18.88	1.492	.333	2.96
	19	0	0		19	0	0	0
R5	17	0	0	0	17	0	0	0
	17.33	1.42	.09	.025	17.33	2.091	1.754	2.05
	17.42	1.06	.09	.046	17.42	2.902	1.936	1.49
	17.5	.78	0	.04	17.5	1.942	1.985	1.33
	17.66	1.06	.105	.031	17.67	1.086	1.446	1.13
	17.75	.92	.09	.012	19	0	0	0
	19	0	0	0				
G9C	17	0	0	0	13.52	1.948	.247	1.6
	17.05	4.3	1.14	.012	17	0	0	0
	17.167	.825	.675	.003	17.17	2.063	2.46	.92
	17.25	.7	.23	.032	17.25	1.918	.247	1.07
	17.33	2.92	.38	.004	17.33	1.668	.631	.88
	17.42	3.28	.57	.229	17.42	1.838	.19	.8
	17.5	.74	.46	.018	17.5	1.754	.039	1.04
	17.75	6.4	.485	.018	17.67	2.159	.426	.93
	18.25	.7	.485	.066	17.75	1.845	2.54	2.05
	18.45	2.06	.39	.003	18.25	1.38	.613	2.96
	19	.84	.38	.004	19	0	0	0
SF3	1823	.7	.035	.031		2.856	1.852	3.18
SF4	1826	.325	.02	ND		2.283	.073	2.96
SF5	1832	5.68	.115	ND		2.98	2.352	3.49
SW4	1715	.78	.025	ND		1.294	1.108	4.1
SW3						3.876	1.966	8.34

JULY 24, 1987.

LOCATION	TIME	AMMONIUM	NITRATE	PHOSPHATE	TIME	CALCIUM	IRON	POTASSIUM
SB1	14.75	0	0	0	14.75	0	0	0
	14.92	.7	.095	.303	14.92	1.202	.245	4.67
	15	.78	.255	0	15	.835	.065	4.8
	15.42	.85	.12	.012	15.35	1.092	1.569	2.26
	17	0	0	0	15.42	.53	.145	2.77
					17	0	0	0
R5	14.75	0	0	0	14.75	0	0	0
	15.02	.45	.025	.004	15.02	1.311	.162	.6
	15.12	.5	.025	.025	15.12	1.052	.426	2.8
	15.18	.56	.01	0	15.18	.794	.684	.82
	15.43	.64	.05	0	15.43	1.038	.168	1.28
	17	0	0	0	17	0	0	0
SF4	14.75	0	0	0	14.75	0	0	0
	14.98	2.34	.27	0	14.95	.842	1.179	3.8
	15.17	.5	.05	.024	15.17	.371	.174	3.2
	17	0	0	0	15.42	1.136	.146	2.4
					17	0	0	0
SW4	15.25	1.6	.05	ND	1547	7.198	.655	4.24
	(hours)	←—— (ppm)	——→		(hours)	←——	(ppm)	——→

JULY 24, 1987,

LOCATION	TIME	AMMONIUM	NITRATE	PHOSPHATE	TIME	CALCIUM	IRON	POTASSIUM
G9C	14.75	0	0	0	14.75	0	0	0
	14.78	.84	.28	0	14.78	1.764	.15	4.67
	14.83	.7	.46	.055	14.86	.493	.039	1.07
	15	.42	.485	.033	14.93	.652	.262	.88
	15.17	.42	.505	.019	15	.784	1.076	.82
	15.25	.5	.255		15.42	.373	.027	.8
	15.33	.52	.56	.012	15.5	.792	1.047	.82
	15.75	.5	.255		15.75	1.198	1.524	1.95
					16.75	.341	.031	5.27
					17	.476	.059	8.26

JULY 28,1987

LOCATION	TIME	AMMONIUM	NITRATE	PHOSPHATE	TIME	CALCIUM	IRON	POTASSIUM
SB2	14.2	0	0	0	14.2	0	0	0
	14.83	.3	0	.596	14.83	.225	.145	3.18
	15	.32	0	.524	15	1.788	3.563	2.67
	15.17	.4	0	.007	15.17	.853	.503	2.8
	15.26	.36	0	0	15.26	1.459	.6	2.96
	15.92	.29	0	.054	15.92	.613	.503	2.96
	17.4	0	0	0	17.4	0	0	0
R5	14.2	0	0	0	14.2	0	0	0
	14.83	.71	0	.03	14.83	.766	1.005	.62
	14.9	.68		.001	14.9	.753	.875	.62
	14.98	.62		.014	14.98	1.037	.375	.8
	17.4	0	0	0	17.4	0	0	0
SF1	14.2	0	0	0	14.2	0	0	0
	14.78	.4	0	.47	14.78	2.376	1.814	6.16
	15.13	.75	.11	.058	15.13	1.504	.294	8.8
	17.4	0	0	0	17.4	0	0	0
SF4	14.2	0	0	0	14.2	0	0	0
	14.85	.7		0	14.25	.343	.4	3.28
	14.93	.52		0	14.93	1.118	1.641	2.67
	17.4	0	0	0	17.4	0	0	0
G9C	14.2	0	0	0	14.2	0	0	0
	14.67	0	0	0	14.72	0	.194	3.59
	14.72	.78	.15	.007	14.83	.381	.249	.8
	14.83	1.28		.003	14.88	.536	.714	.92
	14.88	.42	.35	.648	15.05	1.886	2.395	.92
	15.05	.29	.28	.074	15.22	.381	.249	.96
	15.22	.31	.3	.48	15.42	0	.244	3.23
	15.38	.46	.35	.1425	15.55	.416	.595	1.85
	15.55	.325	.15	.034	15.72	.472	.675	3.59
	15.72	.41	.21	.012	17.4	0	0	0
	17.4	0	0	0				

JULY 30, 1987.

LOCATION	TIME	AMMONIUM	NITRATE	PHOSPHATE	TIME	CALCIUM	IRON	POTASSIUM
SB1	9	0	0	0	1043	.542	.076	4.4
	10.52	.625	.11	.472				
	10.72	.39	.01	0				
	11	0	0	0				
SB2	9	0	0	0	9	0	0	0
	10.57	.43	.08	0	10.57	1.814	.146	7.33
	10.6	.52	.07	.288	10.6	1.073	.135	5.2
	11	0	0	0	10.9	.973	.065	4.93
					11	0	0	0
	(hours)	←—	(ppm)	—→	(hours)	←—	(ppm)	—→

JULY 30, 1987,

LOCATION	TIME	AMMONIA	NITRATE	PHOSPHATE	TIME	CALCIUM	IRON	POTASSIUM
R5	9	0	0	0	9	0	0	0
	9.1	.2	.025	.014	9.1	.341	.132	1.33
	9.27	.725	0	.008	9.27	.717	.084	1.33
	9.6	.675	.05	.202	9.6	1.297	.083	1
	11	0	0	0	11	0	0	0
R6	9	0	0	0	9	0	0	0
	9.07	.75	.01	.198	9.07	.544	.089	4.8
	9.32	.575	.01	.038	9.32	1.398	.118	5.73
	9.57	.75	0	.05	9.52	1.572	.275	8
	11	0	0	0	11	0	0	0

AUGUST 9,1987

		AMMONIUM	PHOSPHATE	DISCHARGE				
SB1	12	0	0	0	12	0	0	0
	12.33	0	0	0	12.6	.115	.153	3.04
	12.5	0	.024	.019	12.78	.476	2.67	3.28
	12.62	.04	0	.041	12.8	.951	.563	2.4
	12.73	0	0	.084	12.97	1.386	.386	2.4
	13	.02	.012	.023	13.08	1.59	.556	2.56
	13.17	0	0	.008	13.25	.091	.386	22
	13.21	.5	.006	.006	13.43	0	.18	3.28
	13.48	0	0	.008	13.58	1.594	.677	2.64
	13.65	0	.008	.006	13.77	1.312	.49	2.96
	13.9	1.28	0	.001	16.25	0	.058	3.36
	14	0	0	0	16.9	1.957	.087	2.88
	14.083	0	0	0	17	0	0	0
	15.67	0	0	0				
	16.1	.02	0	.037				
	16.22	.9		.0105				
	16.25	.84	.006	.0177				
	16.38	.2	0	.008				
	16.48	.2		.0119				
	16.7	.98		.005				
	16.93	.5	0	.002				
	17	0	0	0				
SB2	12	0	0	0	12	0	0	0
	12.33	0	0	0	12.5	1.31	1.919	2.8
	12.5	0	.024	.019	12.62	1.332	.927	3.36
	12.62	.04	0	.041	12.73	.147	.338	2.48
	12.73	0	0	.084	13	1.146	.641	2.16
	13	.02	.012	.023	13.17	.39	.259	2.8
	13.17	0	0	.008	13.48	.548	.163	3.52
	13.21	.5	.006	.006	13.65	1.837	.144	3.36
	13.48	0	0	.008	13.75	.28	.134	3.2
	13.65	0	.008	.006	14.08	.955	.583	2.72
	13.9	1.28	0	.001	16.1	1.254	.618	3.2
	14	0	0	0	16.22	.24	.174	2.88
	14.083	0	0	0	16.25	.086	.127	3.12
	15.67	0	0	0	16.43	.544	1.252	3.44
	16.1	.02	0	.037	16.7	.707	1.288	3.44
	16.22	.9		.0105	17	0	0	0
	16.25	.84	.006	.0177				
	16.38	.2	0	.008				
	16.48	.2		.0119				
	16.7	.98		.005				
	16.93	.5	0	.002				
	17	0	0	0				
	(hours)	←(ppm)→			(hours)	←(ppm)→		

AUGUST 9,1987,

R5

LOCATION	TIME	AMMONIUM	PHOSPHATE	DISCHARGE
R5	12.33	0	0	
	12.5	0	0	
	12.58	.1	0	
	12.67	.28	.012	
	12.75	1.06	.003	
	12.96	0	0	
	13	.04	0	
	13.08	.28	.012	
	13.17	.33		
	13.25	.15	0	
	13.33	.1	.012	
	13.42	.04	.012	
	13.5	0		
	13.8	0	0	
	15.83	0	0	
	16.18	0	0	
	16.35	.1	.012	
	16.78	.18	.026	
	17.05	.05	.02	
	17.1	0	0	

TIME	CALCIUM	IRON	POTASSIUM
12	0	0	0
12.5	1.639	1.806	1.23
12.67	ND	.035	.8
13	.127	.026	1.06
13.08	1.197	.516	.96
13.2	.495	.211	.8
13.25	1.118	.393	.96
13.42	.428	.278	1.12
13.5	1.542	.666	.88
13.67	.336	.146	.88
16.18	.367	.172	.72
16.78	1.875	.116	5.76
17	0	0	0

R6

LOCATION	TIME	AMMONIUM	PHOSPHATE	DISCHARGE
R6	12	0	0	0
	12.6	0	0	.018
	12.65	0	0	.092
	12.68	0	.012	.018
	12.75			.15
	12.86	.2		..0413
	13.033	0	.012	.008
	13.23	.04	0	.001
	13.56	1.06	.02	.001
	13.83	0	0	0
	15.83	0	0	0
	16.12	.6		.018
	16.28	.91	0	.01
	17	0	0	0

TIME	CALCIUM	IRON	POTASSIUM
12	0	0	0
12.65	1.019	.539	1.68
12.68	1.546	1.066	1.76
12.87	.779	.286	2
13.03	1.098	.225	2.08
13.23	3.078	.537	5.12
13.57	1.875	.147	5.76
14.12	.943	.227	1.76
16.28	1.468	.517	1.92
17	0	0	0

G9C

LOCATION	TIME	AMMONIUM	NITRATE	PHOSPHATE
G9C	12	0	0	0
	12.45	.31	.12	.012
	12.62	.2	.39	.026
	12.78	.045	.415	.04
	12.95	.03	.415	.012
	13.12	.18	.53	0
	13.28	.31	.585	.046
	13.62	.2	.46	.026
	15.93	.1	.165	.032
	16.1	.1	.14	.022
	16.26	.2	.12	.026
	16.43	.18	0	.02
	17	0	0	0

TIME	CALCIUM	IRON	POTASSIUM
12	0	0	0
12.62	0	.047	1.36
12.7	1.565	.047	1.2
12.78	.197	.26	.8
12.86	.064	.142	.56
13.03	.636	.548	.48
13.12	1.16	.611	.56
13.2	.149	.051	.4
13.28	1.214	.613	.44
13.37	1.488	.186	.48
13.45	0	.06	1.28
13.53	1.062	.596	.56
13.62	.707	.48	.56
15.85	1.313	.59	.72
15.9	1.315	1.752	.82
16.02	1.471	.057	1.04
16.1	1.426	.116	1.04
16.27	.076	.089	1.28
17	0	0	0

(hours) ←——(ppm)——→ (hours) ←——(ppm)——→

AUGUST 11, 1987

LOCATION	TIME	NITRATE	PHOSPHATE	DISCHARGE
SB1	14.75	0	0	.156
	14.98		.006	
	15.05	.035	0	.122
	15.12	.165	0	
	15.18	.4	.02	.098
	15.25	0	0	.124
	15.36	.185	.006	.049
	15.48	0	.027	.0269
	15.88	0	0	.006
	16.083		.02	.03375
	16.533		.006	.0168

NUTRIENT CONCENTRATION IN RUNOFF,

AUGUST 11	(hours)	(ppm)	(ppm)	(l/s)
SB2	14	0	0	0
	14.97	.07	.015	.26
	15.066	.02	0	.176
	15.2	0	0	.077
	15.3		.01	.1277
	15.38	0	0	.0427
	15.52	0	.006	.02
	15.68			.0104
	15.95		0	.004
	16.18		0	.006
	16.4		0	.005
	17	0	0	0
	18	0	0	0
SF3	14.916	0	.0469	
	15.016	0	.035	
	15.083	0	.0274	
	15.2	.006	.006	
	15.33	.02	.006	
	(hours)			
SF4	15	.08	.02	
	15.08	.035	.094	
	15.17	0	.067	
	15.26	0	0	
	15.42		0	
	15.63		.02	
	(hours)			
R5	14	0	0	0
	14.67	.19	.006	.448
	14.75	.12	.054	
	14.83	.08	.067	
	14.92	0	0	
	15	0	.046	.89
	15.17	0	0	.75
	15.33	.05	0	
	15.45	0	0	.149
	16.05			.0173
	17	0	0	0
	18	0	0	0
R6	13		0	
	14.75	.165		
	14.83	0	0	
	14.916	0		
	15	0	0	
	15.33		.02	
	(hours)	(ppm)	(ppm)	(l/s)

POND	TEMPERATURE	pH
P1	31	7.65
	32	8.05
	34	7.35
	37	7.91
	38	8.31
	40	7.93
P2	30	7.02
	32	7.63
	34	7.15
	36	7.48
	38	7.97
P4	31	8.65
	34	7.11
	34	8.36
	37	8.12
	41	8.02
P5	31	8.11
	32	7.88
	36	8.28
	36.5	7.4
	39	8.28
	(CELSIUS)	

NUTRIENT CONCENTRATIONS IN SOILS
WITH DEPTH.

SITE	DEPTH	NITRATE-N	PHOSPHATE	IRON	POTASSIUM	MAGNESIUM	CALCIUM
	0	0	0	0			
LRSLL	5	1	1.9	5.3			
LRSA	17.5	4	2.5	4.7			
LRSB	28.5	1.3	2.2	4.03			
LRSC	36.5	1.2	3	5.35			
LRSD	48.5	4	1.3	4.8			
	56	0	0	0			
	0	0	0	0			
MRSLL	2	.7	1.5	5.16			
MRSA	11.5	1.6	2.2	3.54			
MRSB	26.5	3.5	2	3.38			
MRSC	41.5	1	1	5.26			
	49	0	0	0			
	0	0	0	0			
URSLL	2.5	2	1.4	2.86			
URSA	10	1	1	3.29			
URSB	22.5	1	2.1	5.55			
URSC	37.5	1	3	4.51			
	45	0	0	0			
	0	0	0	0	0	0	0
LFSA	4	2.8	1	2.62	71.6	23.1	59
LFSB	20.5	1.5	1	2.33	20.1	10.8	41
LFSC	42	1	1.4	2.7	20.9	18.6	39
	51	0	0	0	0	0	0
	0	0	0	0			
MFSA	4	3.2	12.5	2.02			
MFSB	18	1	1.5	2.48			
MFSC	36.5	1.5	2	1.04			
	45	0	0	0			
	0	0	0	0			
UFSA	3	1.4	1	.26			
UFSB	24.5	1.3	1	1.9			
UFSC	43.5	2	1.2	.16			
UFSD	56	0	0	0			
	0	0	0	0	0	0	0
BANA	9	1	6.1	.19	20.4	43.7	220
BANB	25.5	.9	2	.31	19.1	45.6	280
BANC	42.5	1.5	2	.06	85.6	85.3	320
	52	0	0	0	0	0	0
	0	0	0	0	0	0	0
WHAAU	4	16.1	3	.03	59.3	17.9	64
WHBAU	17	.9	1	.07	43.8	60.7	159
WHCAU	33.5	1.8	1.3	.03	36.1	27.1	76
WHDAU	47.5	1.5	1	.08	31.9	29.2	111
	54	0	0	0	0	0	0
	0	0	0	0			
CLLI	2.5	2	1.3	.89			
C15I	12.5	9.7	15	1.56			
C30I	27.5	.5	9.5	1.94			
C45I	42.5	1.9	1	.02			
	50	0	0	0			
	0	0	0	0	0	0	0
P15I	7.5	1.4	1.9	.95	225	63.7	189
P30I	22.5	1	15	.99	527	30.2	95
P45I	37.5	1.4	1.1	.04	26.6	281	47
	45	0	0	0	0	0	0

	0	0	0	0			
WSA	5	1	1	2.26			
WSB	15	3.2	1.3	.86			
WSC	25	7	3.2	.67			
WSD	35	1.7	2	1.19			
	40	0	0	0			
	0	0	0	0	0	0	0
ALL10	5	1.8	1	.02	997	39.7	56
ALL20	15	2.5	1	.01	553.3	23	41
ALL30	25	9	1	.01	21.2	10.5	39
ALL40	35	10	2	.01	24.9	8.5	65
	40	0	0	0	0	0	0
	0	0	0	0	0	0	0
PALLA	8	5	1.3	.02	18.7	15.2	34
PALLB	23.5	9	1	.01	20.7	16.2	48
PALLC	35	.9	1	.02	19.6	12.2	47
PALLD	49	.5	2	.22	21.2	11.6	28
	59	0	0	0	0	0	0
	0	0	0	0			
BSA	7.5	1	1.8	.03			
BSB	22.5	1	1.4	1.38			
BSC	33	3	1.2	.01			
BSD	44	1.1	1.5	.02			
	52	0	0	0			
	0	0	0	0	0	0	0
SPA	2.5	7.8	3	.19	16.6	151	238
SPB	15	9.7	3	.13	50.2	47.9	400
SPC	37.5	3.4	3	.51	47.3	27.1	114
	50	0	0	0	0	0	0
	0	0	0	0	0	0	0
CAO	2.5	1.43	25	.02	72.9	27.2	6670
CBO	14	2.01	22	.036	33.8	30.6	180
CCO	31.5	1.44	2	.036	18	21.5	98
CDO	47.5	.97	51	.01	17.9	26.3	168
	55	0	0	0	0	0	0
	0	0	0	0	0	0	0
P150	7.5	1.47	5	.01	66.4	92.4	230
P450	37.5	1.26	2	.015	25.7	22.1	138
	45	0	0	0	0	0	0
	(cm)	(ppm)	(ppm)	(%)	(ppm)	(ppm)	(ppm)

NUTRIENT CONCENTRATIONS IN SOILS

SITE	NITRATE	SITE	PHOSPHATE	SITE	POTASSIUM	SITE	IRON
BS	1.525	BS	1.475	BS	15.4	BS	.36
RS	1.749	RS	1.91	RS	24.1	RS	4.405
FS	1.7449	FS	2.5	FS	37.5	FS	1.699
WS	3.225	WS	1.825	WS	42.1	WS	1.245
WET	2.5	WET	1.1	WET	163	WET	.04
ALL	3.848	ALL	1.325	ALL	20.05	ALL	.0675
COLL	5.828	COLL	1.25	COLL	274.1	COLL	.0125
CI	3.525	CI	6.7	PI	259.5	CI	1.103
PI	1.27	PI	6	PO	46.05	PI	.66
PO	1.36	PO	3.5	CASS	38.03	PO	.01
CASS	7	CASS	3	WH	42.8	CASS	.28
WH	5.075	WH	1.58	CO	35.7	WH	.053
CO	1.4625	CO	25	BAN	41.7	CO	.0174
BAN	1.13	BAN	3.37			BAN	.187
	(ppm)		(ppm)		(ppm)		(percent)

SITE	MAGNESIUM	SITE	CALCIUM	SITE	PH	SITE	TOTAL ALUMINUM
BS	15.8	BS	40	BS	4.16	BS	8.8
RS	15.7	RS	34	RS	4.33	RS	11.7
FS	17.5	FS	43.6	FS	4.24	FS	8.9
WS	42.7	WS	46	WS	5	WS	9.9
WET	37.5	WET	82	WET	5.24	WET	13.9
ALL	13.8	ALL	39.25	ALL	4.61	ALL	6.3
COLL	20.4	COLL	50.25	COLL	4.43	CI	9.5
PI	40.7	PI	110.3	CI	4	PI	14.2
PO	57.25	PO	184	PI	4.86	PO	9.3
CASS	75.3	CASS	250.7	PO	5.38	CASS	12.8
WH	33.7	WH	102	CASS	4.52	WH	16.6
CO	26.4	CO	1779	WH	4.52	CO	8.6
BAN	58.2	BAN	273.3	CO	4.16	BAN	8.8
				BAN	4.53		(percent)
	(ppm)		(ppm)				

NUTRIENT CONCENTRATIONS
IN UPLAND SOILS.

SITE	NITRATE-N	SITE	PHOSPHATE	SITE	POTASSIUM	SITE	IRON
BS	1.53	BS	1.48	BS	15.4	BS	1.44
SB1	1.5	SB1	1	SB1	12	SB1	.4
RS	1.75	RS	1.91	RS	24.1	RS	4.41
FS	1.74	FS	2.19	FS	37.5	FS	2.1
WS	3.23	SF	4.1	SF	3.9	WS	1.25
GULLY	25.6	WS	1.825	WS	42.1	G9C	.01
G9C	2.2	GULLY	0	GULLY	44		
		G9C	2	G9C	1140		
	(ppm)		(ppm)		(ppm)		(percent)

SITE	MAGNESIUM	SITE	CALCIUM	SITE	PH
BS	15.8	BS	40	BS	4.2
RS	15.7	RS	34	RS	4.3
FS	17.5	FS	46.3	FS	4.2
SF	3.7	SF	8.6	WS	5
WS	42.7	WS	46	GULLY	4.7
G9C	11.4	G9C	40		
	(ppm)		(ppm)		