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ODA Project R4611

Annual Report 1993

The protection role of Jamaican catchment forests and their resistance to and recovery from the impact of Hurricane Gilbert

School of Agricultural and Forest Sciences
University of Wales
Bangor

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Annual Report 1 January - 31 December 1993

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Project Details

Start and finish dates: 1 January 1991 - 30 June 1994

Staff involved:

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Chapter 1

Introduction, objectives and achievements in 1993

Background

The background to this project is the severe disturbance caused to the remaining 13 000 ha of rain forest on the steep hill-slopes of the Blue Mountains of Jamaica. This disturbance is caused by natural forces (primarily hurricanes) and by human ones (shifting cultivation, harvesting of wood and the introduction of exotic invasive species). We have found that the natural forests are very resistant and resilient to the natural disturbance, but much less so to that caused by humans.

The development of solutions to the problems caused by human disturbance cannot be based solely on work within the current areas of forest. Smallholder farming in the Blue Mountains of Jamaica has resulted in all but the highest slopes being cleared of forest cover. A crucial factor leading to the continued encroachment into the remaining forest (often at considerable distances from local communities) is the severe degradation of land formerly under forest cover which now lies at the outside of the current forest buffer zone (Plate 1). The absence of soil conservation measures on these steep slopes, combined with the use of uncontrolled burning and periods of intense seasonal rainfall, has led to very high rates of soil erosion, meaning that present farming practices are unsustainable. Consequently much of this land is now completely abandoned or will support only a very low intensity of agriculture.

The combined effect of the poor state of agriculture on land now outside the forest and the continuing encroachment into the forest (with its greater soil resources) is to cause high levels of siltation within these catchments which have led to further problems downstream, such as periodic flooding, water supply problems and offshore damage to coral reefs and other marine life.

The control of these forest management, land degradation and soil erosion problems is complex, and must incorporate cultural, socio-economic and institutional considerations along with physical and technical solutions. Past soil conservation attempts in Jamaica have had little success despite awareness of the problems and potential solutions, with insufficient funding to the relevant government sector often quoted as the most likely cause.

This study is designed to meet these problems. So far attention has focused on the physical and technical problems within the forest (including the buffer zone where shifting cultivation is currently taking place). However, as the project moves into its major extension and adaptation phase, increasing attention is being paid both to the cultural, socio-economic and institutional aspects and to the need for improved soil erosion control in the catchments outside the forest zone. Should the project be able to continue until March 1995 (in collaboration with the bioengineering expertise of Dr Jane Clark of the Natural Resources Institute), we predict that substantial progress will be achieved in promoting the results of the research.

Objective 1

To determine the effects of forest clearance, agriculture and agroforestry on soil conservation and sustainability.

1.1. Soil conservation and sustainability

1.1.1. Identification of need

The paucity of basic empirical data on rates of erosion under different land uses in mountainous regions has been identified as a serious constraint to the proper scientific management of the Blue Mountains National Park (Kerr, 1991) and the results of this project will meet this need. Therefore, the data from this project should prove to be of great value to the authorities of the National Park in Jamaica and those responsible for similar montane areas elsewhere in the tropics.

1.1.2. Methods

A major field experiment was set up in secondary, buffer-zone forest with four replicated blocks (each being managed by a different partner farmer) and four treatments: undisturbed secondary forest; forest cleared and maintained free of vegetation, forest cleared and planted with agricultural crops, forest cleared and planted with agricultural crops and intercropped with *Calliandra calothyrsus* hedges. In these plots rainfall, throughfall, litterfall, water runoff, sediment yield, nutrient loss in sediment and in solution, soil physical and chemical properties, crop yields and agroforestry tree growth rates are being continuously measured.

1.1.3. Results

1.1.3.1. The buffer zone forest does provide considerable protection to both soil and water resources, even though it is secondary (Plate 2). In particular, the forest acts as a buffer against fluctuations in runoff associated with rainfall events, which may be of particular significance during the large-scale storms which affect the Caribbean region. The forest water storage capacity buffers the system against variations in rainfall amount and intensity. The forest system is also well buffered against sediment loss through erosion (it was very constant over the year of observations, in contrast to the cleared plots). The mean amount of total sediment lost from the forest plots was 0.4 tonnes/ha/yr.

1.1.3.2. Forest clearance leads to marked increases in the rate of erosion and these losses are increased further by subsequent cultivation: clearance of the forest and replacement with bare soil results in a ten-fold increase in sediment loss in the first year and replacement with agriculture results in a thirty-fold increase.

1.1.3.3. Although agricultural use of cleared land does result in increased erosion, its rate (16 tonnes/ha/yr) does not reach the levels predicted from some of the more dramatic figures quoted in the literature.

1.1.3.4. Contour hedgerows do begin to have an ameliorating impact on the rate of erosion loss 9 months after establishment. However, it is not yet possible to tell if the losses will fall to levels that will be acceptable for longer-term sustainability. Therefore, it will be essential to carry on monitoring the experimental plots to determine if the rate of erosion in the agroforestry treatment plots continues to fall relative to the farmed and bare plots, and the extent to which it falls towards the rates in the forest plots before levelling off.

1.1.3.5. Nutrient losses occur at a high rate under agriculture on these steep slopes without erosion control, e.g. up to 70 kg of N/ha lost in one fortnightly period. These are likely to lead to a fairly rapid decline in fertility, a subsequent reduction in crop productivity and possibly a reduction in the rate of forest regrowth after the abandonment of the agriculture. Further results will be required before it is possible to assess the extent to which agroforestry hedgerows will ameliorate this decline through reduction in the rate of nutrient loss and through additional nutrient inputs.

1.1.4. Practical implications

1.1.4.1. The forest cover of the remaining natural primary and secondary forests in the Blue Mountains should be strongly protected. However, the rates of soil erosion under agricultural cultivation are not so high as to require drastic authoritarian intervention with the local farming community. A longer-term, more co-operative extension policy should be acceptable for catchment protection needs.

1.1.4.2. A large extension effort should be made with the communities farming in the upper catchment areas of the Blue Mountains to promote techniques for soil erosion control and more sustainable farming practices.

1.1.4.3. Contour agroforestry hedgerows show considerable potential for meeting these needs. However, existing experimental studies should be continued throughout the second year of cultivation to determine how valuable this technique will be and on what grounds it should be promoted to the local farming community. For instance, it would be a considerable mistake to promote agroforestry on the grounds that it will enable soil fertility to be maintained for a long period of time without fertiliser inputs if this proves to be untrue.

1.2. Long-term forest recovery from disturbance

1.2.1. Identification of need

There is a paucity of quantitative information on the rate of recovery of montane tropical forests from human disturbance either in terms of the rate of increase of biomass, of species diversity or of soil structure and fertility. This information is vital for the development of scientifically-based management of such forests to meet the multiple objectives of protecting catchments, biodiversity and the needs of local people for forest products.

It is important to be able to assess the length of time taken for the forest to recover to its original biomass, so that the time-span needed for any cycle of repeated cutting of the forest to be sustainable can be assessed. In protected areas of high conservation status, it is also vital to assess the extent to which the species diversity of the forest recovers after the cutting. Given the long time taken for a forest to complete a single growth cycle, assessment of the long-term sustainability of forest use also requires quantitative information on the extent to which the soil condition of the forest recovers. These considerations would apply both to cutting of the forest for extraction of timber and fuel-wood and to clearance of the forest for shifting cultivation.

1.2.2. Methods

Two studies have been carried out. In the first, the regrowth of forest following cutting and extraction of wood has been studied over a 14-year period. The rate of recovery of biomass has been studied by the harvesting of sub-plots and detailed mensuration of the growing trees with a 2-yearly enumeration interval. The rate of increase in biomass and height and the rate of recruitment and survival of stems have been quantified separately for each species and for stems of seed origin and basal sprouts.

In the second study, three blocks were chosen where stands of primary (> 150 years since disturbance) and secondary (< 30 years since disturbance) forest were in close proximity. Four soil pedons (pits) were dug in each plot (24 in total), the soil profile was described and soil samples were collected for physical and chemical analysis.

1.2.3. Results

1.2.3.1. Following the cutting of a small patch of montane forest in Blue Mountains and the removal of all the standing biomass, the rate of recovery of forest biomass was very low (264 g m^{-2} yr^{-1}). The projected time period required for the forest to recover to its original biomass is 125 years.

1.2.3.2. The rate of recovery of the tree species diversity of the forest is very slow. So far, there is no evidence that the cut gap will return to its original tree species diversity. This is probably largely due to the dominance of *Pittosporum undulatum* suppressing the regeneration of native species.

1.2.3.3. Initial analysis of the soil data indicates that the structure of the soil in primary and secondary forests was similar in terms of profile and particle size composition. The chemical analyses of the soil samples and the investigation into the land-use history of the sites will be carried out next year.

1.2.4. Practical implications

1.2.4.1. The natural forests of the Blue Mountains are not suitable for short-rotation harvesting for forest products. 125 years is the minimum return period possible for a harvesting cycle. Repeated disturbance of the forest within that time period might well lead to more severe longer-term degradation.

1.2.4.2. Widespread cutting of the forests in the Blue Mountains is likely to lead to a longer-term loss in biodiversity.

1.2.4.3. Therefore, it is recommend that the Blue Mountains National Park develop alternative strategies for satisfying the needs of local people for forest products. Disturbance of the remaining natural forest should be kept to an absolute minimum, and any proposals for 'sustainable' extraction of products from the natural forest should be considered extremely carefully. The results of this study provide clear scientific data which can be used by the park management to oppose any unsuitable proposals.

Objective 2

To assess the impact of the hurricane on the tree species in the natural forest and their subsequent recovery using ground survey.

2.1. Identification of need

The impact of Hurricane Gilbert had a devastating effect on the economy of Jamaica. Amongst the most serious of its impacts was on catchments in which there was large scale flooding, landslides, erosion and damage to forest resources (especially plantations of *Pinus caribea*). This brought to attention the need for land-use planning to consider which vegetation types were most suitable for catchment protection in this hurricane-prone region (GOJ,UNDP & FAO, 1990). As well as identifying the resistance and resilience of different natural vegetation types to hurricane impacts, it is also vital to determine which facets of the resistant natural vegetation (species and structure) should be incorporated into planted forests to improve their hurricane-resistance.

2.2. Methods

2.2.1. A wide-ranging ground survey has been carried out of the impact of the hurricane, and subsequent recovery of different forest types in the Blue Mountains.

2.2.2. Detailed re-enumeration of existing permanent sample plots has allowed the specific effects of the hurricane and the resistance and resilience of different tree species to be recorded precisely.

2.2.3. A full analysis has been made of the extent of sprouting in response to damage of different tree species.

2.2.4. The development of regrowing vegetation in permanent sample plots in severely disturbed area of forest has been studied. Interpretation of the results from this study are focusing on identifying the factors that most closely predict the future composition of the vegetation, which is an essential source of information for forest management.

2.3. Results

2.3.1. The natural forests were, on average, very resistant to hurricane impact. Initial mortality was only 7.2% of stems. However, there was great variation between sites.

2.3.2. The natural forests did suffer considerable defoliation (100% in one third of the forest area). However, the rate of recovery (resilience) of all the natural forest types was great. As the canopies refoliated subcanopy light levels declined exponentially, such that by 28 months after the hurricane there was no significant difference between the subcanopy light levels in forests which had suffered different levels of hurricane damage.

2.3.3. Resprouting in response to damage was very common in the natural forests. 61.4% of 4949 living stems and 44 out of 47 abundant species had sprouts. The presence of sprouts was significantly correlated with stem survivorship.

2.3.4. From all of the separate studies that we have carried out, we have identified the species of greatest potential suitability for tree planting programmes in different environments. For this selection we have used data of the natural abundance of the species in different site types (including fire-dominated areas and land-slides); their hurricane resistance; their sprouting ability; their growth and survival rates in different environments; their competitive ability; and their wood density. A full list of these species is given in the Conclusions (Section 11) and the best species are listed in the Practical Implications below.

2.3.5. The future composition of forest stands after natural disturbance is predictable from the early condition of the vegetation. For shade-tolerant species, height at time of gap creation is one of the main predictors of subsequent success and for light-demanding species, early germination after gap creation and rapid growth during the first year predicted subsequent success.

2.4. Practical implications

2.4.1. The natural forests of the Blue Mountains provide the best available protection against hurricane impact and associated down-stream damage in catchments. Therefore, the highest priority should be attached to their conservation and re-establishment in the most vulnerable deforested areas.

2.4.2. A considerable number of the native tree species would be suitable for tree planting programmes. The most highly recommended species are: *Dodonaea viscosa* var. *angustifolia* in the most fire-prone sites; *Alchornea latifolia* for better-protected open sites; *Eupatorium critoniforme* for moderately shady enclosed sites; *Eugenia virgultosa* for very shady sites (e.g. below an existing canopy); *Clethra occidentalis* for land-slides. Sources of seed and the suitability for vegetative propagation of these species should be determined and trial plots and demonstration plots should be established in different environments as soon as possible.

2.4.3. In the management of tropical montane forests for the conservation of given endangered tree species or for the silvicultural promotion of given economic tree species, pre-disturbance regeneration sampling is of potential value for determining which species will regenerate successfully after natural or human disturbance. In addition, two post-disturbance samples within the first 18 months will be required for the more light-demanding species. During this sampling the relative heights of the seedlings and saplings of the different species must be recorded, and a sub-sample of individuals must be labelled for re-enumeration and height growth measurement.

Objective 3

To compare the impact of Hurricane Gilbert on mountain forests differing in aspect, altitude and slope using satellite imagery.

3.1. Identification of need

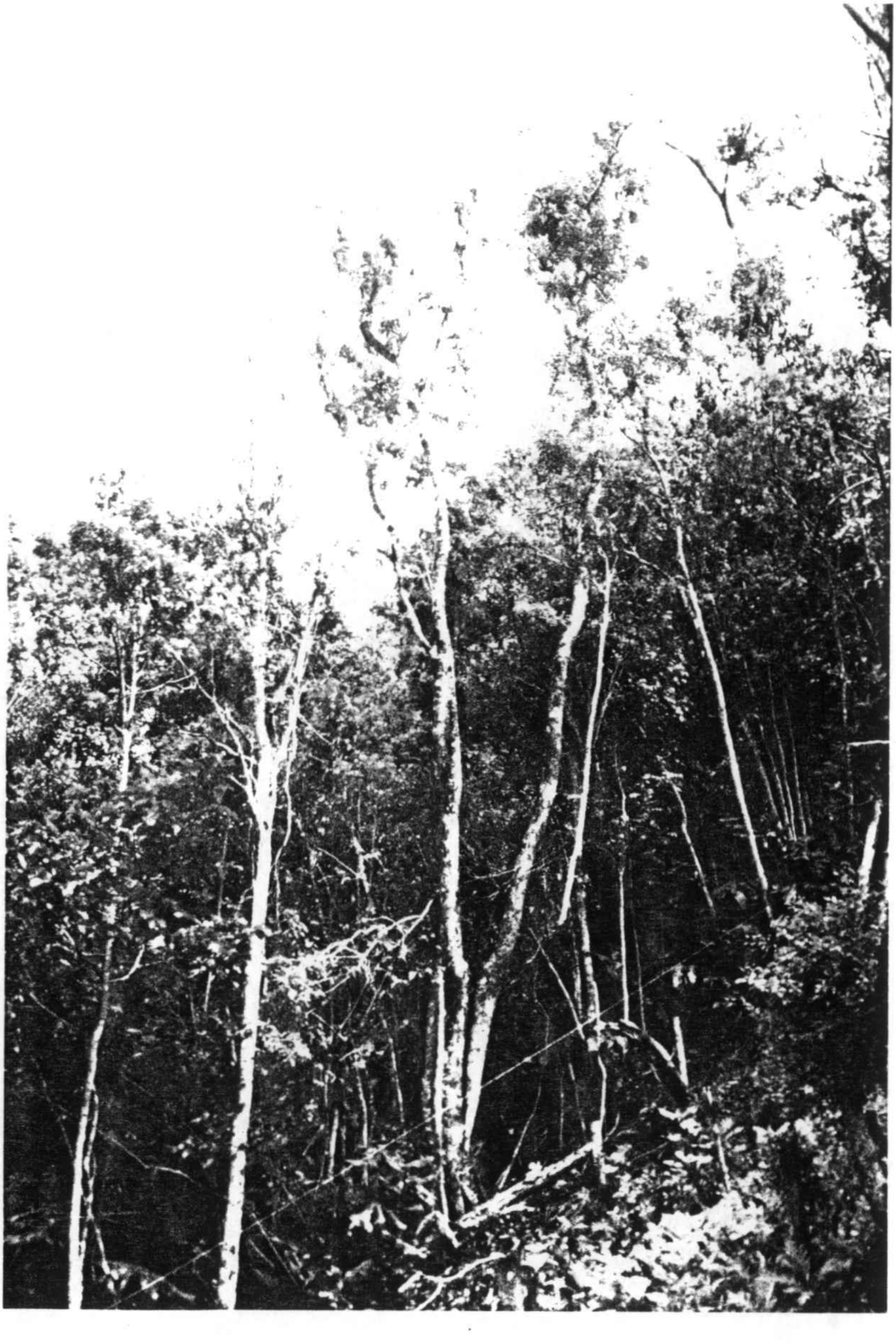
The need for this work is largely as described for objective 2 (above). The only addition is that land-use planning in Jamaica requires information on the vulnerability of different site

Plate 1 Degradation of previously forested land at the outer edge of the current forest buffer zone.

a) Clearance of land for agriculture using fire.

b) Land abandoned from agriculture and subject to repeated burning which has become a degraded grass-dominated 'savanna'.

Plate 2 A cross-section of secondary forest from the edge of one of the cleared treatment plots showing the density of foliage throughout the profile.



types to hurricane impact. Although the exact properties of each hurricane differ, those striking Jamaica share common features, especially their arrival from an easterly direction. Given the detailed record that exists of hurricanes in the Caribbean region during the past 120 years, it is now possible to predict the probability of any given site suffering severe damage from future hurricanes. Although there will be a considerable degree of error in predicting the impact of any single hurricane, there will be much less in predicting the net effect of all the hurricanes striking in a 60-year period. Such information will still be of great value for long term land-use planning in Jamaica.

3.2. Methods

3.2.1. Satellite images of the Blue Mountain region before and immediately after Hurricane Gilbert have been analysed using a new technique that allows hurricane damage to be quantified. The results of this analysis have been compared with ground survey data.

3.2.2. Should this project be able to continue until March 1995, these results will be analysed using a Geographical Information System. As well as allowing a more powerful comparison of the correlation between different site types and degree of hurricane damage, this will allow us to produce a large scale maps of the Blue Mountains showing the distribution of damage caused by Hurricane Gilbert and the risk of future hurricane damage.

3.3. Results

As reported previously, damage to forests was correlated with their general topographic position. Little new work has been done on this objective during the current year. The next phase of this work will take place in March 1994 when Dr Kapos travels to the University of Washington to collaborate with Dr Adams.

Objective 4

By working with local farmers and the Jamaican authorities, to promote the use of the research results. Using the data on the impact of forest harvesting and conversion to other land uses, we will develop guidelines and systems for soil conservation, and produce appropriate technical manuals and extension material.

4.1. Identification of need

Refer to the background information at the start of this section.

4.2. Methods

4.2.1. A review has been carried out of the past experience of integrated catchment management, farmer extension activities and the promotion of soil conservation techniques in the Blue Mountains region and in similar montane environments in other developing countries.

4.2.2. The main experimental part of this project has been designed with extension as an integral part of the project. Through the four partner farmers working in each of the experimental blocks, close contacts have been established with the local farming community. Formal and informal meetings have been conducted. Full advice and assistance has been provided to farmers interested in tree planting.

4.2.3. A more formal socio-economic survey of the local farming community focusing on their attitudes to soil conservation has been started in collaboration with the University of Wageningen.

4.3. Results

4.3.1. The use of trees for erosion control has proved to be popular amongst local farmers and several have adopted the system for their own use, with the assistance of project staff. The agroforestry plots within this project have encouraged a considerable number of local farmers to plant, not just hedgerows, but a number of options including farm borders and live fences involving a number of species. Because of the interest generated by our project, a considerable demand has been created for tree seed and seedlings. We have advised the staff of Cinchona Botanic Garden in how to meet this need by establishing a seed collecting programme and a nursery. As a result the garden has become a centre of seed and seedling distribution for the local community over the last twelve months.

4.3.2 The influence of the project has also affected larger land-owners in the region, who have increased the rate of tree planting on their plantations over the past 18 months.

4.4. Practical implications

In the large scale watershed management and rural development forestry projects planned for the Blue Mountain region under the auspices of the Jamaican National Forestry Action Plan and other initiatives:

1. Planning should be carried out with a long-term perspective, using a basic framework which develops from a small-scale intervention, through a building phase, to a fully integrated project.

2. A diagnostic survey using a relaxed and participatory approach should be carried out to obtain background information about the current situation.

3. A series of demonstration plots and on-farm trials should be established, and managed by researchers and farmers in partnership, so that a range of ideas can be tested and adapted, thus increasing the chances of adoption.

4. Land and tree tenure issues must be carefully considered. Experience in other countries must be carefully considered.

5. Future extension programmes should be developed from the small-scale efforts already made. The approach, both in terms of design and management control, must be carefully planned.

6. A full project appraisal and cost-benefit analysis should be carried out in order to consider the potential impacts of project implementation. The inclusion of environmental and social benefits into an economic analysis may help to justify the project on economic grounds.

Chapter 2

Previous achievements in 1992

1. A major field experiment was set up to investigate the effects of forest clearance and subsequent land use on soil conservation and water retention in the buffer zone of the natural forest. Four replicate blocks were established (each being managed by a different partner farmer) and four treatments (further details are given in Chapter 3).

   One paper on this part of the project was delivered at an international conference and another was published in a professional newsletter. Two BSc dissertations were completed on the condition of the soil under different land-uses in this area.

2. The analysis of the first phase of the remote sensing data was completed. Using a new "mixing model" analysis of LANDSAT TM-based satellite imagery, the areas of forest in the Blue Mountains that had suffered different degrees of damage from Hurricane Gilbert were mapped. It was found that damage is relatively unrelated to aspect and that shelter is a much more important factor.

   A draft of a paper on this work was completed ('Hurricane damage to Jamaican montane forests assessed by analysis of Landsat TM images').

3. Ecological research was carried out into the impact of a severe hurricane and human disturbance on the natural forests of the Jamaican Blue Mountains and their subsequent recovery.

   A paper was presented at an international conference in which the evidence provided by this research for the predictability of natural regeneration following disturbance was reviewed.

   Two MSc dissertations were completed. In the first the rate of coppicing from cut stumps and sprouting from damaged trees was assessed. The incidence of both coppicing and sprouting was high: coppice shoots completely dominated the biomass in one cut plot. 84% of species were found to have a capacity to coppice and 93% to sprout.

   In the second MSc dissertation, the three-dimensional structure of an area of natural forest was analysed and it was discovered that the tree crowns occur at a high density, are frequently columnar and that there is a lack of canopy stratification. These factors contribute to the catchment protection provided by the natural forests.

   One BSc dissertation was completed on the biogeography of the native tree species. This showed the high level of endemism of the tree flora, especially the species whose regeneration is most dependent on undisturbed conditions.

Chapter 3

An experimental investigation of the effects of forest clearance, agriculture and agroforestry on water runoff, soil conservation and sustainability

M A McDonald, J R Healey & P V Devi Prasad

SUMMARY

The study has been running successfully since the imposition of the treatments in September 1992, and the plots have been continuously monitored over that period.

The project rationale and methodology are described in this report, as are some of the preliminary results from the study. Some discussion of the data is made to give an overview of the project's findings, but at this stage, the data analyses are incomplete. Full data analyses will be incorporated into the final report.

INTRODUCTION

The Blue Mountains are a geologically recent tropical mountain range, characterised topographically by steep slopes and highly dissected terrain, with sharp ridges and deep gullies. Natural soil development is poor, owing to a combination of steepness of slope and significant erosion. The natural vegetation is montane tropical rainforest (Shreve, 1914).

The forest has a long history of clearance, most recently for two major land uses - cash crop cultivation by small farmers and the establishment of coffee plantations (Eyre, 1987). The hydrological and erosional impact of these land-use changes are complex. Replacement of a tropical rain forest canopy with an agricultural crop has been shown to increase water yields by between 110-825 mm in the first year after clearance. However, the reduced infiltration following forest removal may result in more overland flow and consequently greater flood peaks and reduced dry season flows (Bruijnzeel, 1990). Indeed, there is increasing concern about the impact that contemporary deforestation has had on water resources in the Yallahs Valley, the catchment into which most of the montane head-waters of the southern slopes of the Blue Mountains drain. The two bodies responsible for water resource management in Jamaica, the National Water Commission and the Underground Water Authority, have both implied that deforestation has resulted in reduced water yields during the dry season, increased the magnitude and frequency of downstream flooding and increased turbidity of river water as a result of erosion (R. Cover and B. Fernandez, pers. comm.).

Despite the inferences made as to the effects of forest clearance in the Blue Mountains, there is a lack of basic empirical data and understanding of the effects of forest clearance on the fertility of the soil and its continued productivity. There is a need to gauge the response of the land to the various changes of use by the measurement of a standard selection of soil properties and ecosystem processes, related to nutrient and water cycling, soil physical factors and soil biological processes. Thus, if it is a basic tenet that the control of soil erosion is only one aspect of soil conservation, then in practical development planning, erosion should not be treated in isolation, but integrated with maintenance of soil fertility, water availability and other aspects of agricultural improvement.

Agroforestry systems will be very important in realising these objectives. Agroforestry is best described in this instance as a land-use system in which trees or shrubs are grown in association with agricultural crops with the objective of stabilising and sustaining productivity. It has been practised in Jamaica for many centuries, but not in any disciplined manner (Suah and Nicholson, 1986), and not to any great extent on mountainous, steeply-sloping agricultural lands. There is a need to investigate suitable systems for these environments, and to assess their contribution to the control of soil erosion and maintenance of soil fertility.

The importance of the remaining forests in the Blue Mountains as a biological resource, from the point of view of their influence on water and soil conservation as well as being a unique ecosystem containing a high number of endemic species, has been acknowledged, and this area has been incorporated into a new National Park. The Park contains two contiguous but strikingly different mountain ranges: the Grand Ridge of the Blue Mountains extending from roughly east to west, and, at the easternmost end of the Blue Mountains, the massif of the John Crow Mountains, extending from south-east to north-west. the National Park has an area of over 77,000 hectares and contains seven distinct forest types (Grubb and Tanner, 1976); it represents the largest expanse of continuous undisturbed forest in Jamaica. Thus, contemporary land-use issues in the Blue Mountains are those of preventing further deforestation, instigating buffer-zone management and ensuring sustainable alternatives in areas originally cleared of the natural forest.

These are amongst the objectives of the current study into the catchment protection role of Blue Mountains forest. The principal objective of the study is to investigate the consequences of forest clearance on soil conservation, in the context of soil fertility as well as soil erosion. The potential benefits of using an agroforestry system - hedgerow intercropping - for soil conservation is also being investigated.

STUDY AREA

The study area is located to the south-west of the main ridge of the Blue Mountains in the watershed of the Green River, a head-water tributary of the Yallahs River. The elevation is around 1500 m, and the Yallahs Basin as a whole has a high natural propensity for soil erosion (McGregor *et al*, 1985). These factors lead to poor soil development: soils generally being acidic clay loams, usually less than 1 m deep, with stony subsoils (GOJ/UNDP/FAO, 1982). Average rainfall is about 2000 mm and shows clear seasonality with a major wet season around October/November and a smaller peak in May. Mean monthly temperatures are between 18.5 and 20.5 °C, with absolute maxima of 21.5-24 °C and extreme minima of 8.5-10 °C (Government of Jamaica Meteorological Office, unpublished data).

The land-use history of the area is well documented by Barker and McGregor (1988) and McGregor *et al.* (1985). During the early colonial period, the area remained under forest cover, and it was not until the eighteenth century that the European settler economy began clearance, initially for coffee, and later for cinchona and tea. Cultivation techniques were poor, with little use of 'shade' trees and clean weeding between bushes resulting in erosion and degradation. The plantations' slave workforce grew their own food in small plots of land, often on the steeper forested hill-slopes above the main areas of plantation crops.

This may have constituted a system of shifting cultivation. Much of the land was subsequently abandoned and today much of it has reverted to unproductive scrub land or secondary ('ruinate') forest. The other major factor influencing the evolution of the landscape was the rise of small-scale agriculture after emancipation in 1838.

Historically, clearance for agriculture was rarely accompanied by appropriate soil conservation techniques, and often resulted in excessive erosion and land degradation (Finch, 1952). The Yallahs Valley Land Authority (YVLA) was initiated in 1951 to provide integrated planning and development for agriculture in the Blue Mountains (Floyd, 1970) and was responsible for allocating land to tenant farmers, introducing new agricultural production techniques, implementing soil conservation measures and providing technical support to farmers. Unfortunately, the focus of this progressive initiative was lost with the dissolution of the YVLA in the 1970's, and cultivation of cash crops such as escallion, thyme, carrots and peppers is now largely by a system of rotation, with clearance by fire being widespread prior to crop establishment (Barker and McGregor, 1988).

METHODS

Experimental plots have been established in:

1. Secondary forest (Plate 3)

2. Forest area cleared, burned and subsequently maintained weed-free (Plate 4a)

3. Forest area cleared, burned and planted with agricultural crops

4. Forest area cleared, burned and planted with agricultural crops and intercropped with *Calliandra calothyrsus* hedges (Plate 4b).

Four blocks each containing one plot of each treatment have been established in the Green River Valley in areas of secondary forest, originally cleared for coffee, cinchona or agriculture and subsequently abandoned. Each plot is 10 m x 20 m, with an inner assessment plot 8 m x 15 m. The plots were cleared in July, 1992 in accordance with local practice - smaller trees were removed with cutlasses, and the larger ones with axes. The plots were subsequently left to dry until August and then broadcast burned. The plots were left for up to three weeks to 'sterilise the soil' (the local practice) and planting of trees and crops began in September, 1992. Currently, escallion, thyme, carrots, 'Irish' potatoes, beetroot, cabbage, sweet pepper and cucumber are amongst the major crops cultivated in the area for subsistence and sale in the local markets. A mixture of these crops has been established in the agricultural plots. The rationale for the hedgerow intercropping system is given in Chapter 1. The hedging system was designed after Young (1989) and involves three hedgerows per plot. The hedgerows are 5 m apart and comprise triple rows of trees at 1 m intra-row spacing and 0.5 m inter-row spacing (Plate 5). The rows are arranged in a staggered manner downslope to maximise the area of coverage.

Plate 3 A control undisturbed forest plot showing Gerlach trough, gutter and collecting bucket. Note the deep layer of litter covering the soil surface on the forest floor.

Plate 4 Cleared forest treatment plots showing Gerlach troughs and collecting buckets.

a) Bare soil clean-weeded treatment.

b) Agroforestry treatment.

All the photographs in this report were taken in March - May 1993, 6 - 8 months after the start of the experiment.

The trees were grown from seed collected from naturalised *Calliandra calothyrsus* trees in and around Cinchona Botanic Garden during February and March 1992. The seeds were sown in March, 1992 in seed trays, transplanted to pots after germination, and kept in a shade house at the Botanic Garden until outplanting at a height of about 30 cm. The hedges have been cut back four times over the last year, starting when they reached a height of approximately 1 m. They were cut back to about 30 cm, and never allowed to grow more than about 1 m tall, at which point they started to shade the crops (Plates 6 and 7). Initially, the prunings were used to fortify the hedges (Plate 8), but subsequently, they were chopped up and used as mulch on the farmed area between the hedges. Biomass production was recorded and details of this will be presented in the final report.

Although only one tree species is being examined in the main trial, a subsidiary experiment was been established to compare the relative growth rates and coppicing abilities of *Acacia mearnsii*, *Pittosporum undulatum*, *Paraserianthes lophantha* (all species naturalised in Jamaica found growing locally) and *Clethra occidentalis* (a native species). Details of this study will be presented in the final report.

Forest conversion to other land-uses involves gross disruption of nutrient cycles and water balances. The magnitude of this disruption is being assessed by monitoring temporal changes in:

1. Runoff

Three Gerlach troughs have been installed in each plot (Morgan, 1979). The collecting gutter is covered with a lid to prevent the direct entry of rainfall. Sediment and runoff is channelled from the gutter into collecting buckets. Samples have been collected on a fortnightly basis since September, 1992. Total volumes of runoff have also been recorded and sub-samples filtered and retained for nutrient analyses. Bulked samples from each plot have been analysed once a month for:

- Dissolved (K, Ca, PO_4-P, NO_3-N, NH_4-N, OC)
- Total (P (Org-N + NH_4-N)N).

Total mass of sediment eroded is also recorded, and the entire sample separated into particulate organic matter, and coarse (>3 mm) and fine (<3 mm) mineral fractions. A bulked sample of the sediments collected from each plot over the first year has been compiled and will be analysed in the same way as the soil samples described in Section 5 below.

2. Interception

A data-logging rain-gauge was established at each block to record the amount and intensity of rainfall (Plate 9). Nutrient contents of bulk precipitation have been assessed twice over the experimental period.

Throughfall collectors to measure effective precipitation reaching the soil surface were placed in the forested plots. Five collectors totalling 1 m^2 in area were set up in each plot, and have been emptied and relocated on a fortnightly basis. Quantities were recorded and bulked samples collected on a plot basis each month for nutrient analyses as described for runoff above.

Plate 5 An agroforestry plot showing contour hedgerows and a farmer at work, which is a major cause of erosion. Note the degraded land beyond the forest boundary.

Plate 6 Dr Morag McDonald (Project Officer) and Mr Roy Bryan (partner farmer) making the first pruning of a *Calliandra* hedgerow after 6 months.

Plate 7   Dr McDonald weighing the prunings from one *Calliandra* tree.

Plate 8 Mr Bryan laying prunings along the hedgerow to improve erosion control during the hedge's early development.

3. Organic matter inputs (quality and quantity)

Five litter traps of approximately 1 m^2 total area were placed in each of the forest plots. These are being emptied on a monthly basis, the contents dried and weighed, and will be separated into leaves, small woody litter and reproductive structures. The samples will be bulked by three month increment and analysed for nitrogen and carbon content as an index of litter quality.

4. Decomposition rates

Pittosporum undulatum (a species with a narrow genetic range growing ubiquitously in the area) litter leaves were collected to use as a standard decomposition substrate. Five replicates of known quantities of the material were placed in each plot. It had been planned to collect subsamples on a three monthly basis and record weight-loss. However, although the first collection was made successfully, subsequent macrofaunal activity destroyed the leaves and no further collections have been made.

5. Soil structure and nutrient availability

Three soil cores were collected from each plot prior to clearance in June, 1992, and analysed for:

- Stone content
- Particle size analysis
- Organic matter content
- Bulk density
- pH
- Total N, P, K, Ca, Mg
- Available (Bray's) P
- Exchangeable Na, K, Mn, H, Ca, Mg and Al
- Base saturation percentage

The soil sampling was repeated in October, 1993, except that six samples were collected from the *Calliandra* plots - three from under the trees and three from between the hedges in the farmed area. The analyses will be repeated over the winter of 1993. All soil analyses will be included in the final report.

RESULTS

A very large volume of data has been collected over the last year, and, as yet, it has only been subjected to very preliminary analyses. However, some data are presented in Figures 1 - 14, and preliminary conclusions drawn from them. Full presentation of all the data, including standard errors, and complete analyses will be presented in the final report.

Rainfall

Rainfall amounts and intensities are presented in Figure 1. The dates of the sampling intervals referred to in this and all subsequent figures are shown below Figure 1. The total rainfall for the year September 1992-September 1993 was 2415.9 mm, which is average for the location. There were two distinct wet periods, with approximately 20% and 30% of the annual total falling in January and May respectively. The highest intensity of rainfall of 360 mm/hr was recorded during an event in January. There were several events of high intensity recorded over the year, ten yielding values of more than 100 mm/hr.

Runoff

Figures 2 and 3 present total runoff on an areal basis and as a percentage of rainfall respectively. These data need to be separated for rainfall events, and statistical relationships established. However, the trends shown would seem to indicate marked differences in patterns between treatments. All treatments show a positive relationship with rainfall amount and intensity, most acutely with the three cleared treatments, which also show greater amounts of runoff. When expressed as a percentage of rainfall, the forest plots show the least fluctuation, suggesting that the forest water storage capacity buffers the system against variations in rainfall amount and intensity. The farmed plot without agroforestry hedging displays the highest runoff as a proportion of rainfall. Runoff values expressed as a percentage of rainfall are low compared with other studies which record values ranging from 0.4% to as much as 34% (Lundgren, 1980) for a range of land uses - suggesting good infiltration in all of the treatments. Infiltration capacities have not yet been determined.

Figures 4-8 show loss of nutrients dissolved in runoff water. Again, there are marked differences between treatments, corresponding to larger volumes of runoff. Nutrient losses over the course of one year may be a significant loss to the system - up to 70 kg N/ha lost during one fortnightly period (N input in rain is about 26 kg/ha/annum). N & P losses vary with rainfall amount, losses being higher from the cultivated treatments (Figures 4 and 5). Losses of the mobile forms of P & Ca are high and vary with rainfall amount (Figures 6, 7 and 8). Losses of K were due to mobilisation after the burn, particularly so in the bare plot which had no vegetation to capture the nutrients in the runoff. However, subsequent losses are low for all treatments (Figure 8).

Sediment yield

Figure 9 and Plate 10 show that there are marked differences between the treatments in sediment yield over the first year of collection. The cultivated treatments show consistently higher losses, with peaks relating not only to rainfall, but also to periods of intense farmer activity: planting, weeding and harvesting (e.g. January (planting), March and April (weeding), June (harvesting) and September (planting)). Figure 10 expresses the sediment yield as a proportion of rainfall, and indicates that losses may also be correlated with previous rainfall conditions.

Separation of the sediments into particulate organic matter, and coarse (>3 mm) and fine (<3 mm) mineral fractions indicates that most of the variation between treatments arises from greater amounts of coarse sediments eroded from the cultivated plots (Figures 12 and 13). There is less difference in organic matter losses between treatments (Figure 11), with proportionately more occurring in the bare and forest plots.

When cumulative totals of erosion losses for three month periods are presented (Figure 14), it would seem that the forest system is well buffered, showing very consistent sediment yields over the experimental period. The bare plots showed consistent loss over the first nine months. However, there was a considerable increase in the last three months (June-September 1993), even though this period was one of the driest in the year (474.7 mm of rainfall, compared with 465.2 mm in months 0-3 (September-December 1992), 669.8 mm in months 3-6 (December 1992-March 1993) and 806.2 mm in months 6-9 (March-June 1993). This may be a consequence of debilitated soil structure due to the preceding wet period, coupled with drying and crumbling. The soil analyses and subsequent data collections will

Plate 9 Dr McDonald logging data from one of the automatic tipping bucket rain gauges.

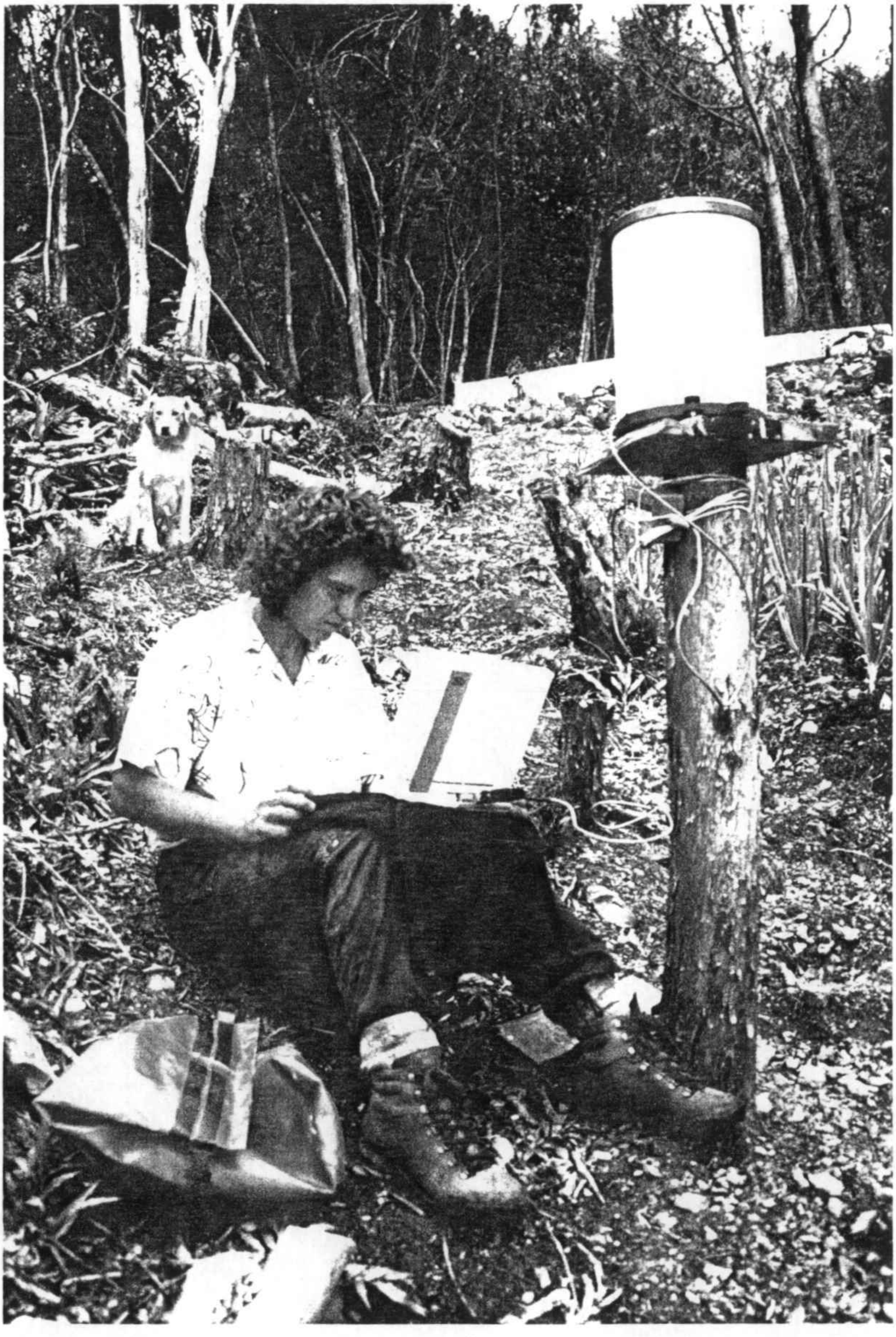


Plate 10 Eroded material accumulated in Gerlach troughs during a 2-week collection period.

a) Control undisturbed forest plot: mostly leaf litter with little soil.

b) Agricultural crop plot: a large quantity of eroded soil.

be instructive in interpreting these data. The cultivated plots show consistently higher erosion losses, with a similar trend to that shown by the bare plots. The difference between the farmed plot and the farmed plot with *Calliandra* hedging becomes more marked with time - presumably as a result of the tree growth providing a more substantial hedge, and the prunings providing ground cover. Finally, the total sediment yields (Figure 15) over the first year of data collection show that there are significantly higher sediment losses after forest clearance, and especially if subsequently cultivated. These effects are partially offset by the use of contour hedgerows.

DISCUSSION

The runoff losses and sediment yields measured in the bare and agricultural plots in this study are low compared with other published studies from steeply sloping wet tropical sites. However, the erosion losses under forest are similar to those recorded by other workers (e.g. Maass *et al*, 1988). Published estimates of soil erosion in Jamaica vary from 17 tonnes/ha/annum (Governmental experimental station 1980-1984) to over 100 tonnes/ha/annum (e.g. Champion, 1966; GOJ/UNDP/FAO, 1982). However, many of these estimates were not derived experimentally but from the Universal Loss Equation and are likely to be over-estimates of the actual situation. These figures do not allow for sediment sinks in individual fields and in the catchment as a whole, nor do they take into account the counterbalancing effect of soil conservation structures such as the ones present in this study. There is room for optimism that the presence of *Calliandra* hedgerows reduces the rate of erosion to around 10 tonnes/ha/annum. Morgan (1986) reviews literature relevant to a humid tropical area such as Jamaica, and suggests that the rate of soil formation is around 10 tonnes/ha/annum; i.e. the presence of hedgerows on agricultural land in our study area reduces the rate of erosion to that which is considered acceptable in the humid tropics. However, the consequences of nutrient losses from these plots may be highly significant, and it remains to be seen whether the addition of mulches from the hedges will compensate for these losses. The analyses of these data will be completed this winter.

The data from this project should prove to be of great value to the authorities of the National Park in Jamaica and those responsible for similar montane areas elsewhere in the tropics. The paucity of basic empirical data on rates of erosion under different land uses in mountainous regions has been identified as a serious constraint to the proper scientific management of the Park (Kerr, 1991) and the results of this project will meet this need.

With respect to agroforestry, the demonstrated use of trees as contour barriers is, of course, only one option in the encouragement of tree planting in the area. The National Park management plan incorporates a number of options including the planting of timber trees, windbreaks, border planting, the use of trees in agriculture for soil conservation and beautification and deals with concomitant issues such as nursery establishment and production of extension material. The plan also considers the issue of land tenure, which, if insecure, can be a significant deterrent to a farmer to invest the time and resources for tree planting. Many farmers in the area have limited or no legal tenure, and the National Park authorities will be negotiating such rights on an individual basis with farmers. Rights to tenure within already cleared areas within the Park boundaries and a buffer zone extending 2 km from the Park boundary will be decided on the suitability of slope steepness for agriculture and the current cropping procedures. Lease rights may be exchanged in return for park boundary maintenance, or on condition of tree planting exercises (Robert Kerr, pers. comm.). If farmers are to be evicted from 'unsuitable' areas, these areas will be replanted using a range of tree planting options. With these sorts of lands in mind, a study has been initiated in conjunction with Dr Jane Clark of the Natural Resources Institute to

Plate 11 An agroforestry plot with *Calliandra* hedgerows and a crop of escallion.

screen species for use in bio-engineering projects for erosion control of degraded steeplands and unstable slopes (Chapter 14).

Widespread promotion of planting of species such as *Calliandra calothyrsus* should be treated cautiously, however. The naturalised population around Cinchona Botanic Garden originated from seed originally obtained from a single source in Southern Guatemala and thus represents a very limited genetic base (MacQueen, 1992). It may well be the case that germplasm from a different provenance would be far superior in the conditions described. There is a need for the formal testing of different provenances under local conditions. The introduction of any foreign germplasm should also be subject to careful controls. Experience in Europe has indicated that the time period required for an introduced species to become naturalised and potentially a threat to natural biodiversity may be around 150 years (Klaus Amman, pers. comm.) and there may be several examples of this phenomenon in the Cinchona area. The most notable of these is *Pittosporum undulatum*, a tree native to south-eastern Australia. One hundred and twenty years after its introduction to Cinchona Botanic Garden, much of the secondary forest on the southern slopes near to the garden is dominated by this species, and further away it forms a dense understorey of saplings (Healey *et al.*, 1992). It is now presenting a significant threat to biodiversity in areas of undisturbed forest. However, on many steep sites it represents the sole tree cover slowing soil erosion, and it may have regenerated there under conditions where native species would have been unable to regenerate; it is also a popular local fuelwood, providing an abundant supply of dense wood, which burns well when green, coppices readily and shows high growth rates (Healey *et al.*, 1992).

The challenge is to manage *Pittosporum undulatum* and other species to maximise their potential without furthering their spread. There is a need to establish demonstration plots using a variety of species and techniques. The agroforestry plots within this project have encouraged participation by demonstration, and project staff have assisted a number of local farmers to plant, not just hedgerows, but a number of options including farm borders and live fences involving a number of species. Because of the interest generated by our project, Cinchona Botanic Garden has become a centre of seed and seedling distribution for the local community over the last eighteen months.

CONCLUSIONS

Although only speculative conclusions can be drawn at this stage because of the incomplete analysis of the data, it would seem that considerable protection is offered to both soil and water resources by the forest, even though it is secondary. In particular, the forest acts as a buffer against fluctuations in runoff associated with rainfall events, which may be of particular significance in large-scale storms. Agricultural use of cleared land does result in increased erosion, but not as much as anticipated, and the use of contour hedgerows reduces erosive losses to levels that may be acceptable for longer-term sustainability. However, nutrient losses may lead to a decline in fertility and subsequent reduction in crop productivity. It remains to be seen whether a hedging system will ameliorate this. The use of trees for erosion control has proved to be popular amongst local farmers, and several have adopted the system for their own use with the assistance of project staff.

Figure 1 Total rainfall between sampling dates (mean of 4 blocks)

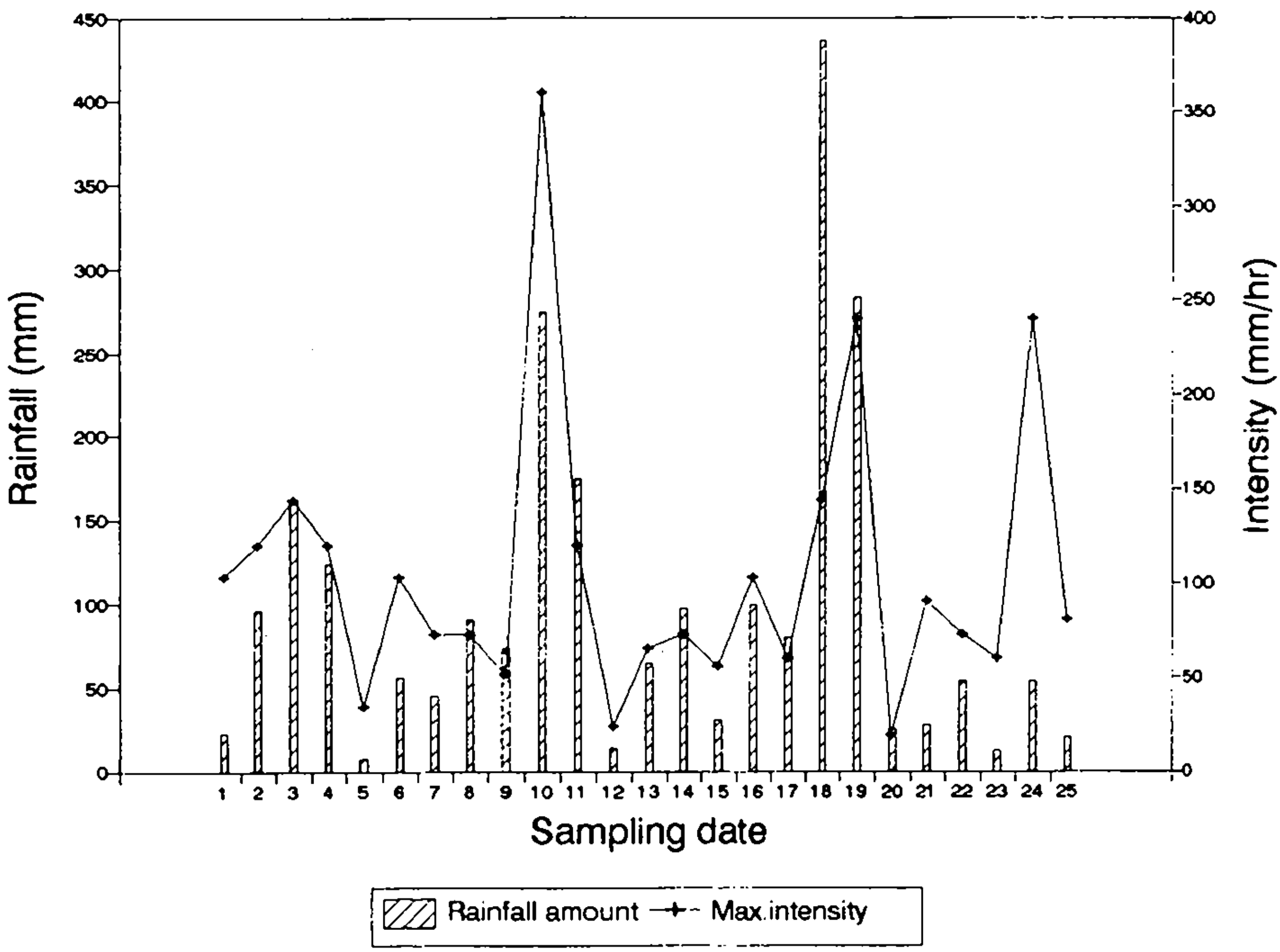


Table 1 **Sampling dates**

1	14-9-92	8	27-12-92	15	12-4-93	22	3-8-93
2	21-9-92	9	7-1-93	16	25-4-93	23	16-8-93
3	8-10-92	10	27-1-93	17	6-5-93	24	31-8-93
4	26-10-92	11	8-2-93	18	24-5-93	25	14-9-93
5	9-11-92	12	22-2-93	19	8-6-93		
6	27-11-92	13	8-3-93	20	29-6-93		
7	7-12-92	14	22-3-93	21	19-7-93		

NB For figures 2-15 the values shown are the means of the 4 plots in each treatment.

Figure 2 Volume of runoff water per surface area of plot

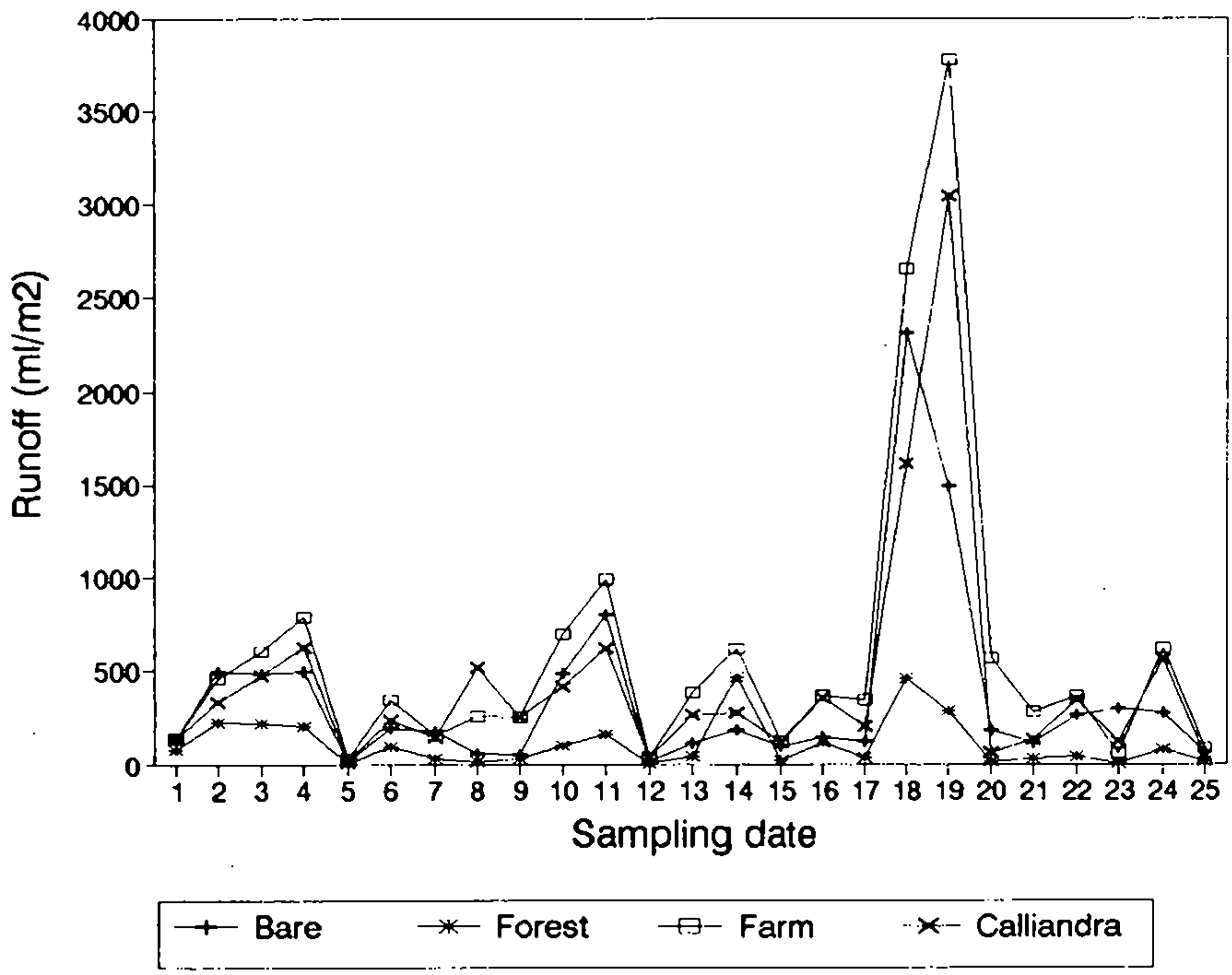


Figure 3 Volume of runoff water as a percentage of the volume of rainfall falling on each plot

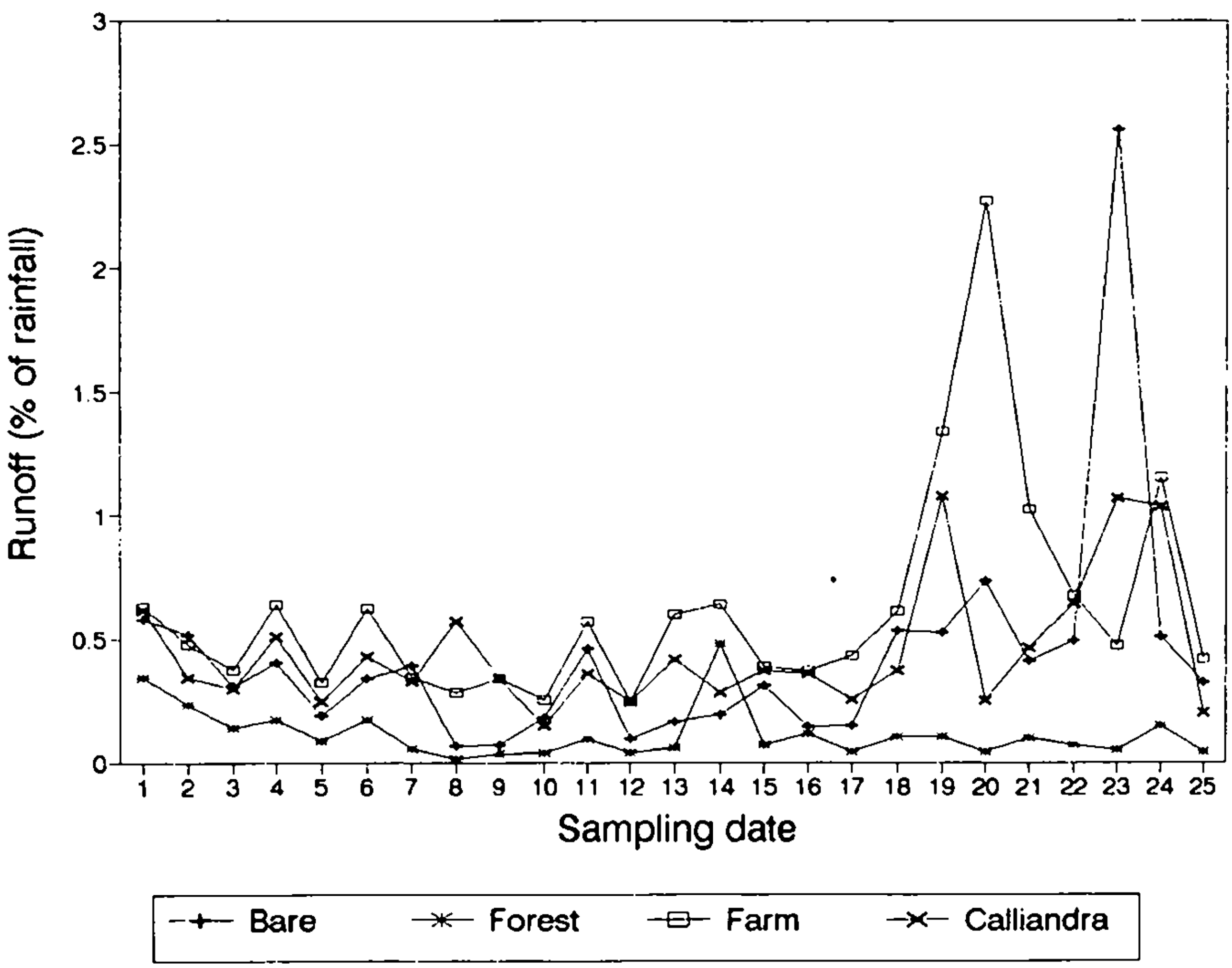


Figure 4 Amount of dissolved nitrogen lost in runoff water from plots per unit area

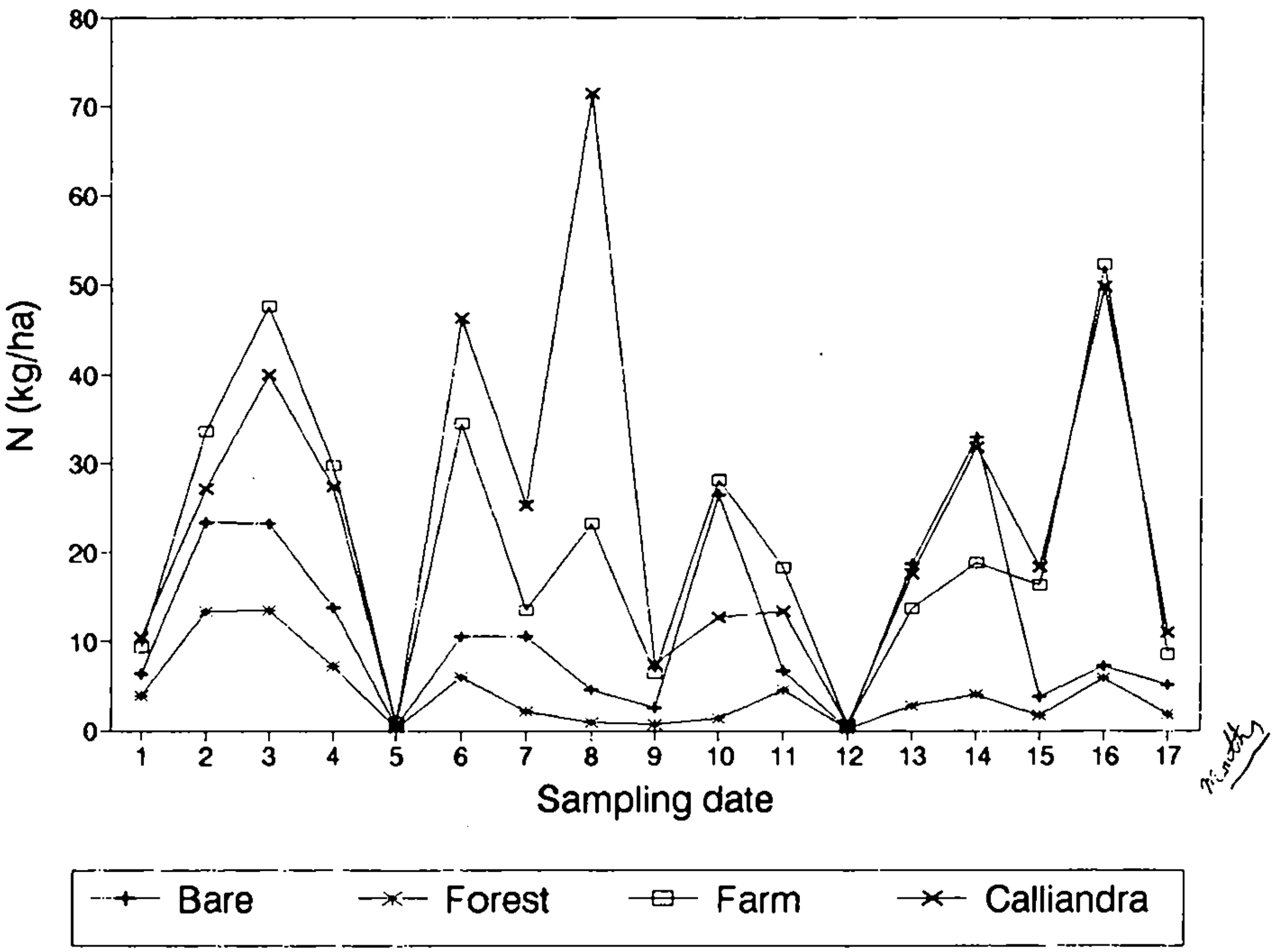


Figure 5 Amount of dissolved phosphorus lost in runoff water from plots per unit area

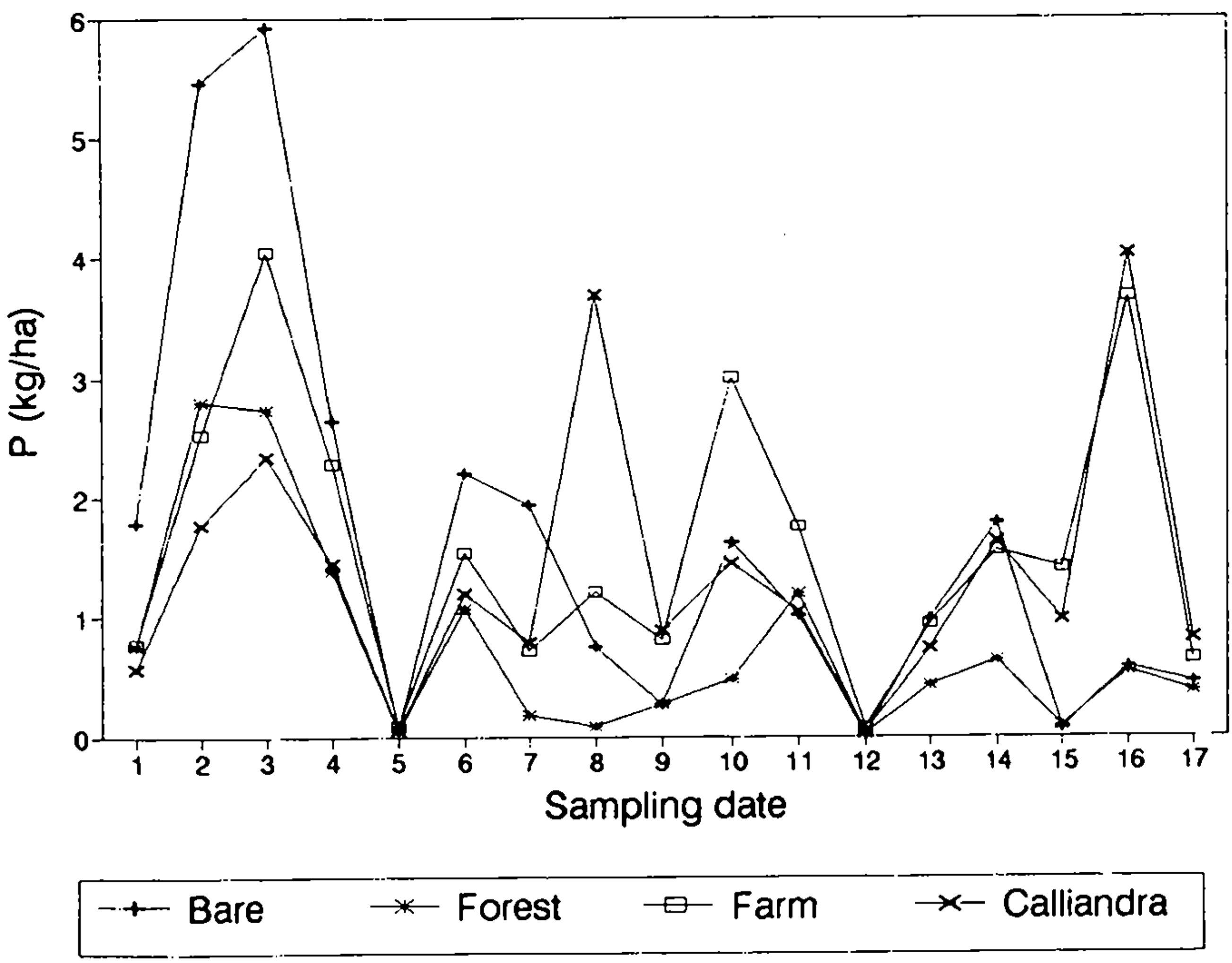


Figure 6 Amount of dissolved phosphate lost in runoff water from plots per unit area

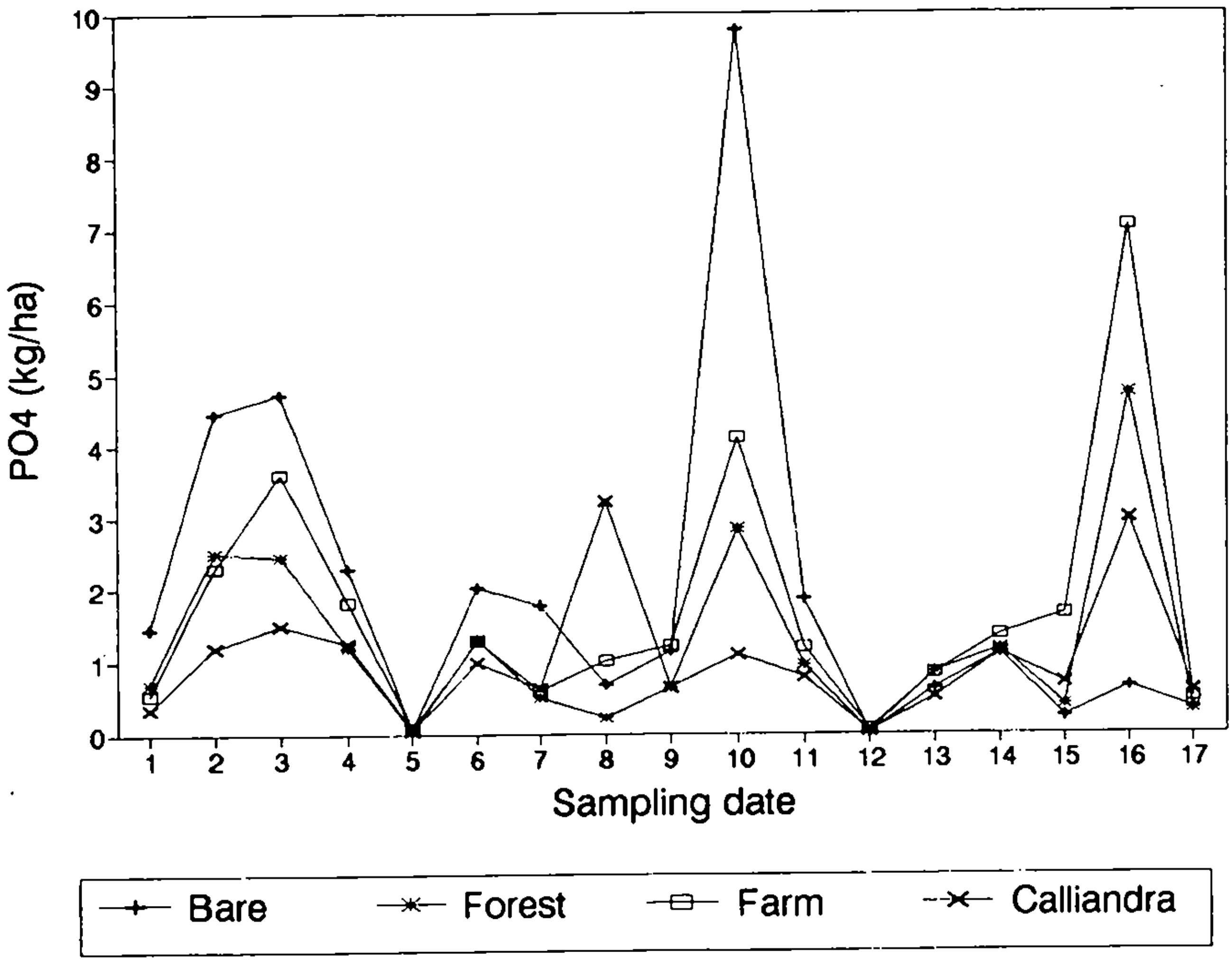


Figure 7 Amount of dissolved calcium lost in runoff water from plots per unit area

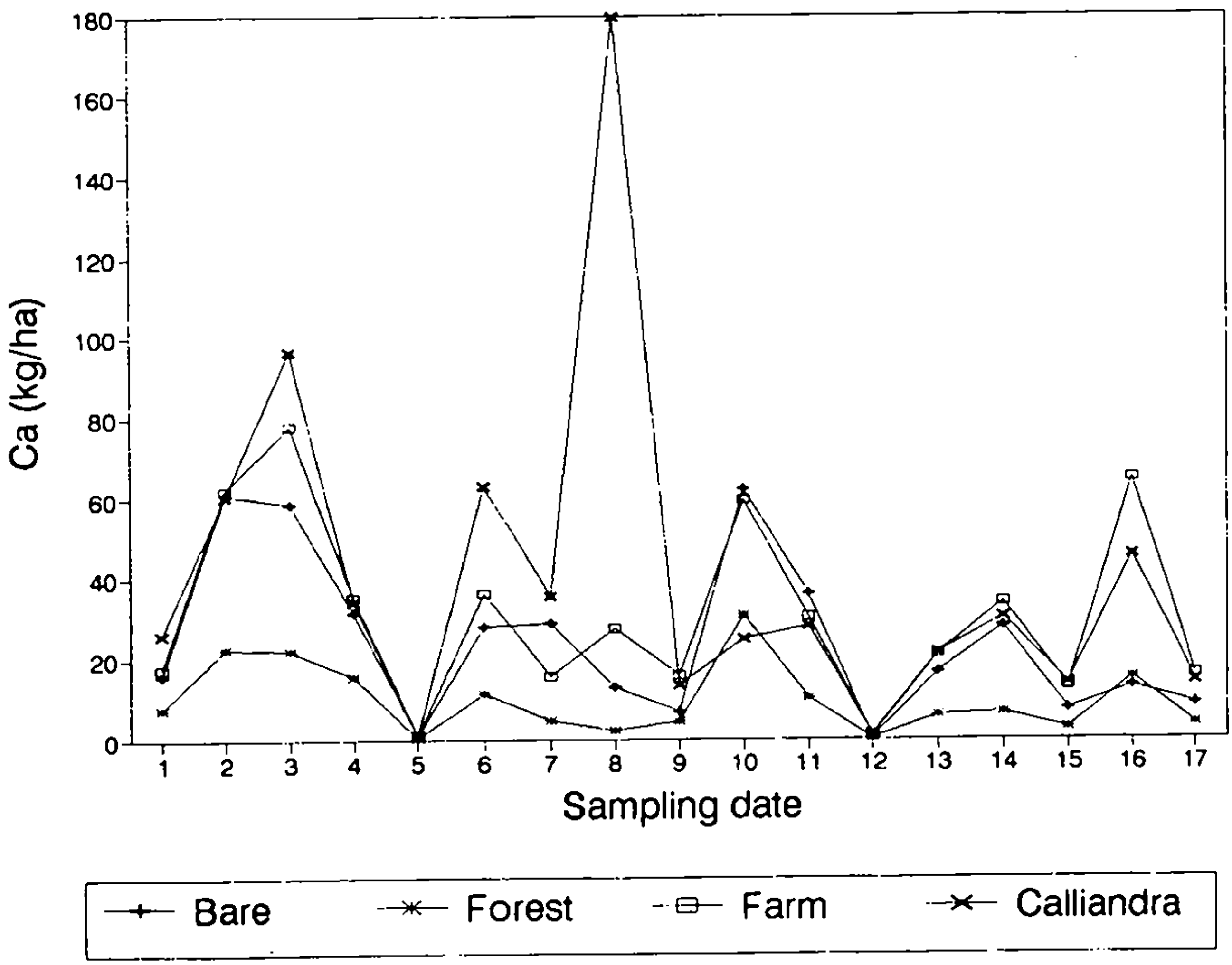


Figure 8 Amount of dissolved potassium lost in runoff water from plots per unit area

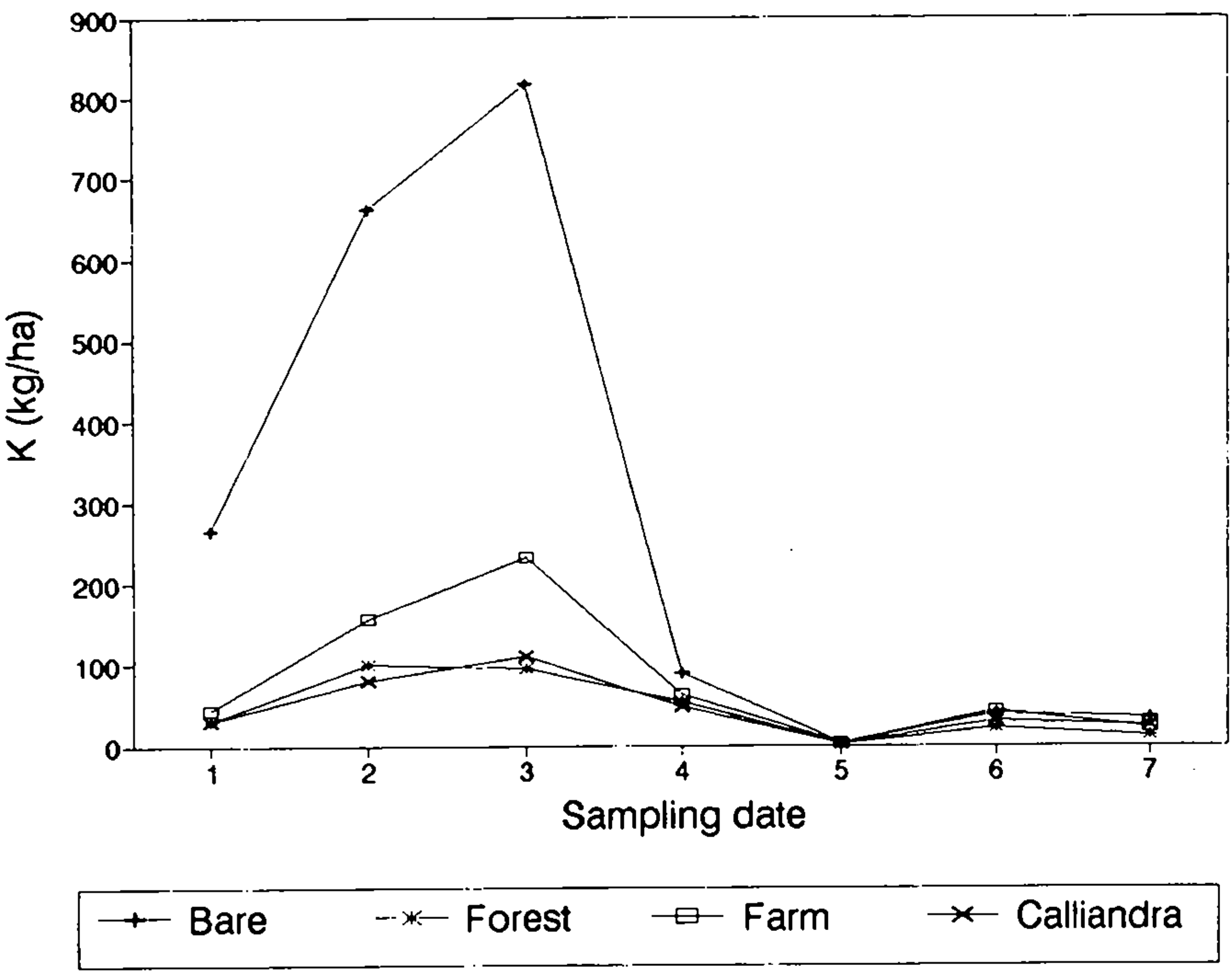


Figure 9 Total amount of eroded material lost from plots per unit area

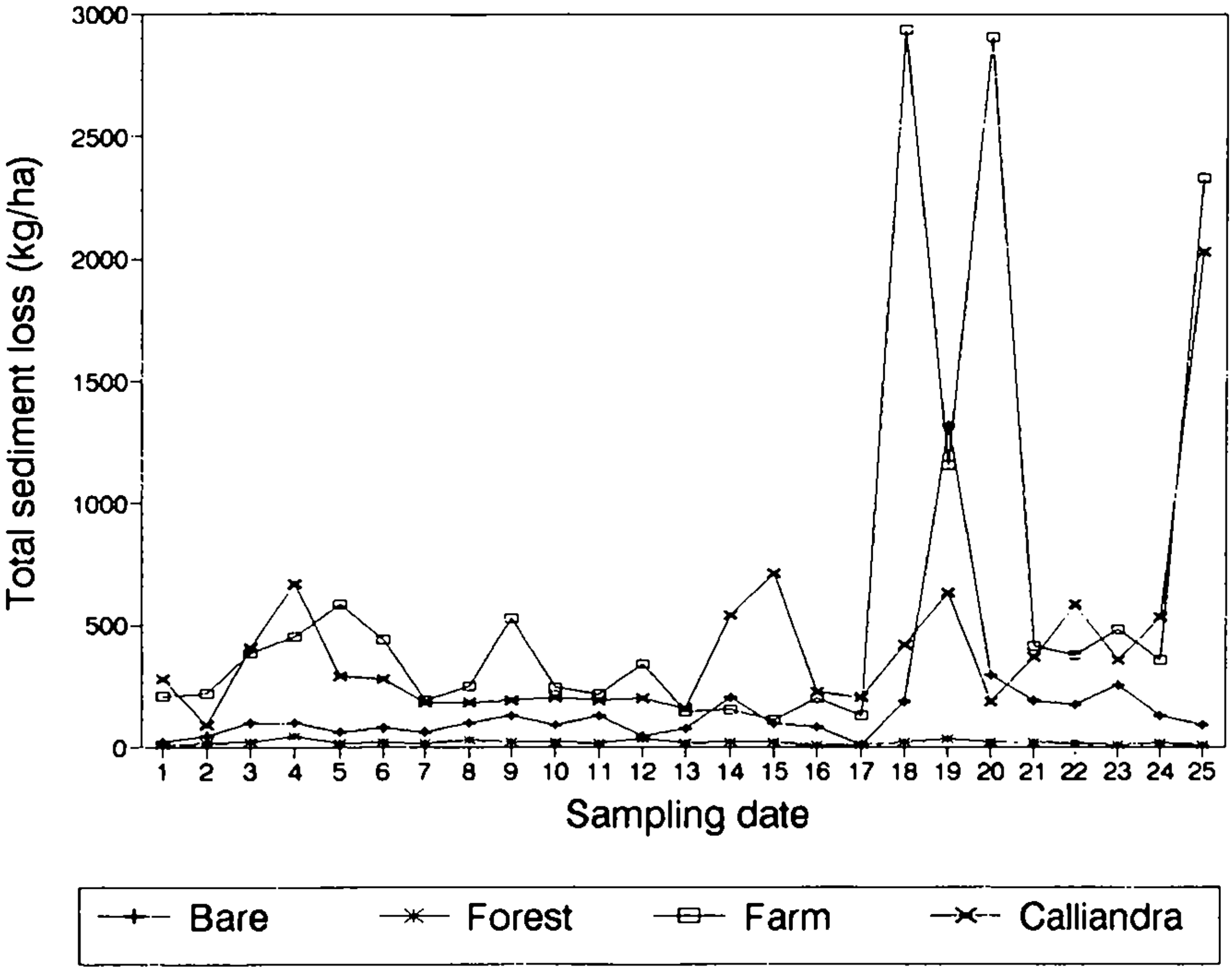


Figure 10 Total amount of eroded material lost from plots per unit area expressed as a proportion of rainfall

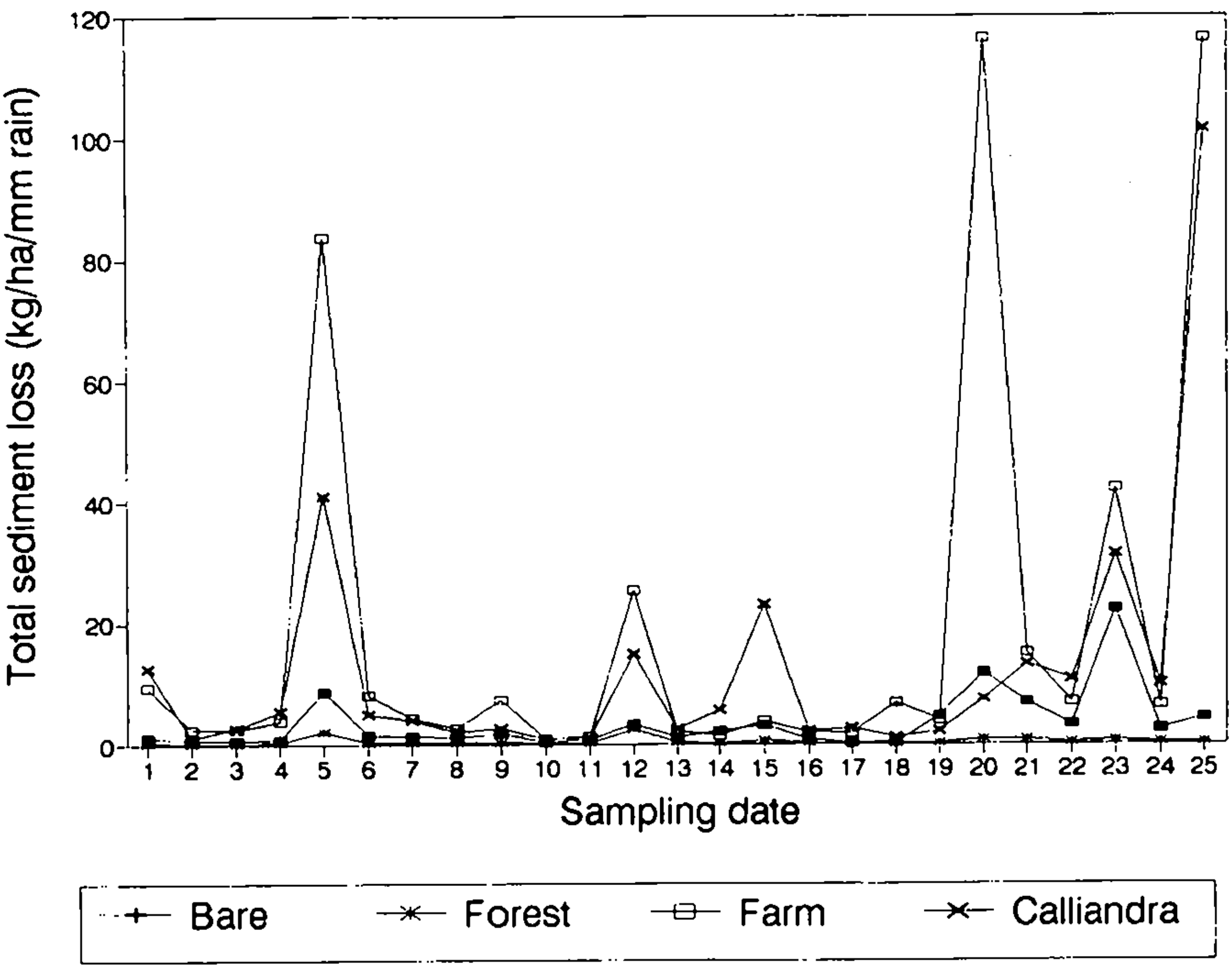


Figure 11 Amount of eroded particulate organic matter lost from plots per unit area

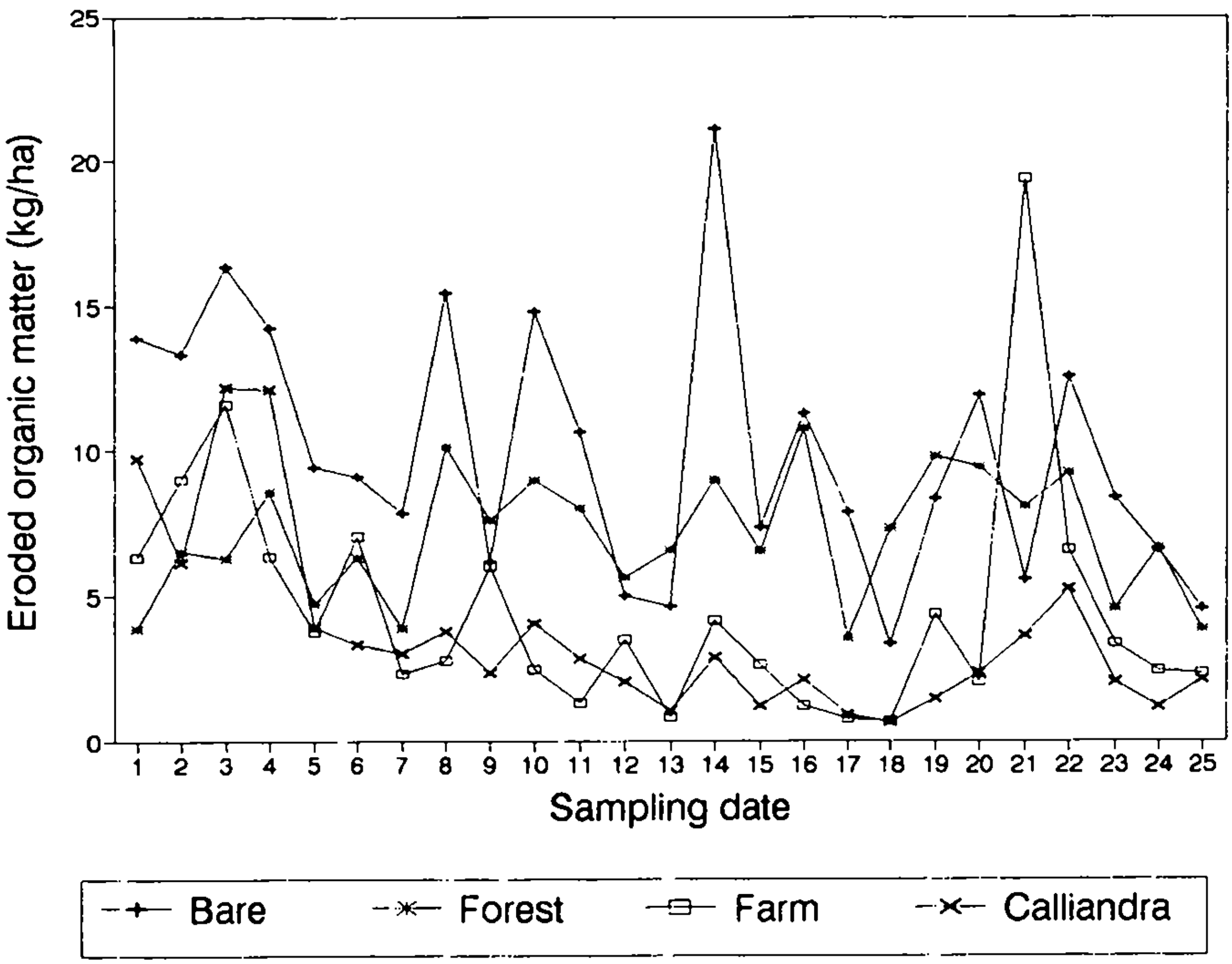


Figure 12 Amount of eroded fine sediment (<3 mm) lost from plots per unit area

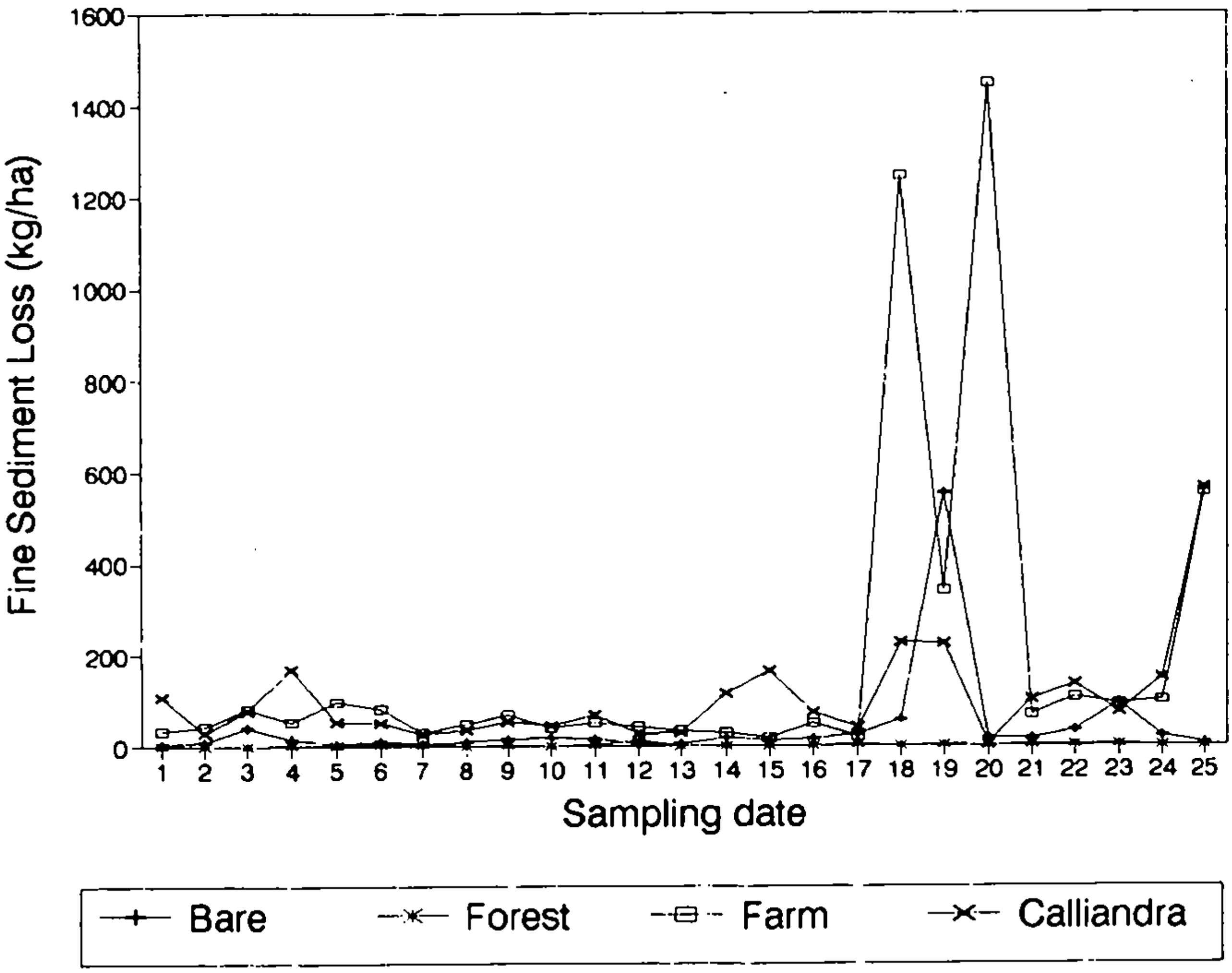


Figure 13 Amount of eroded coarse sediment (>3 mm) lost from plots per unit area

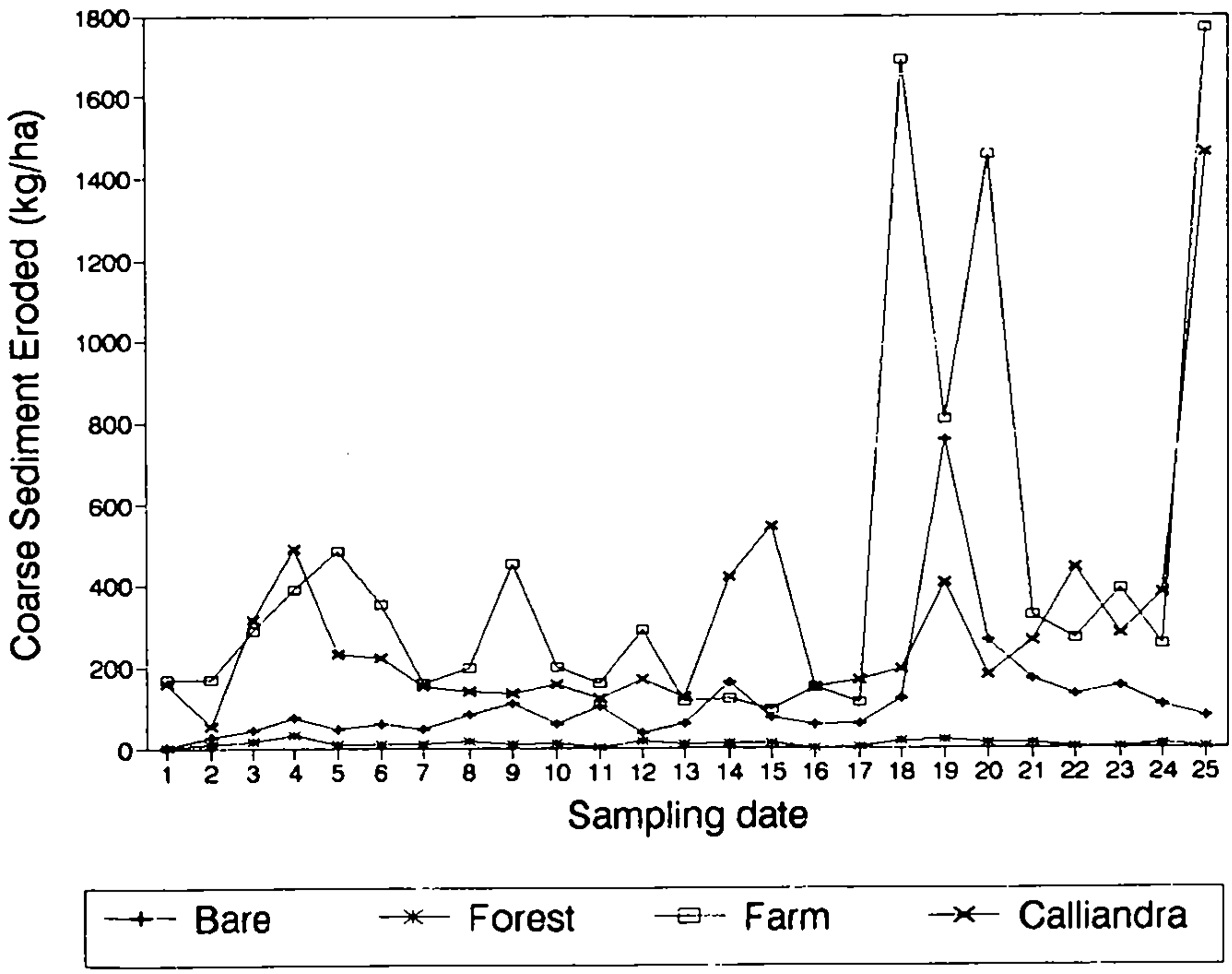


Figure 14 Cumulative 3-month total amounts of eroded material lost from plots per unit area expressed as a proportion of rainfall

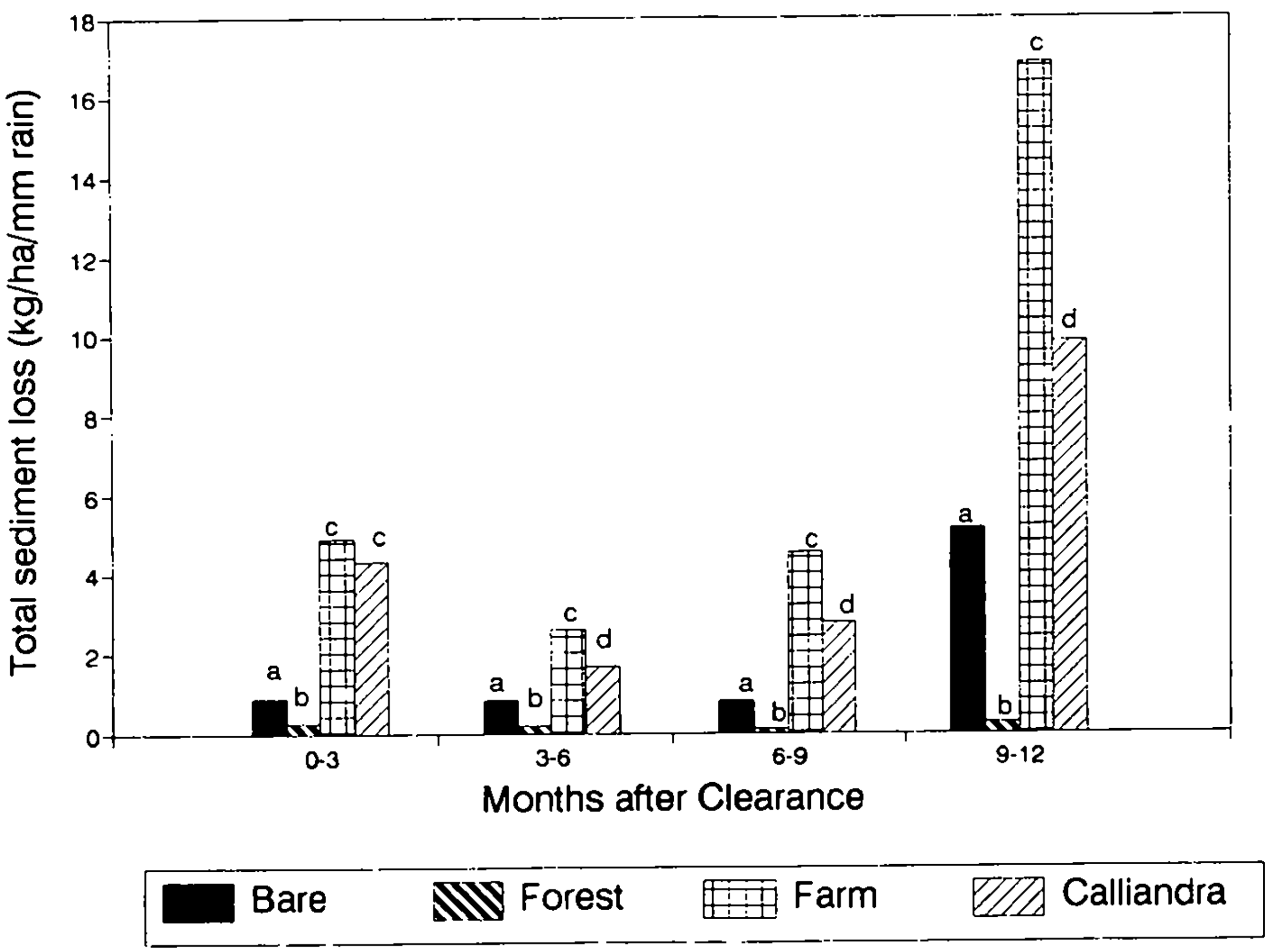
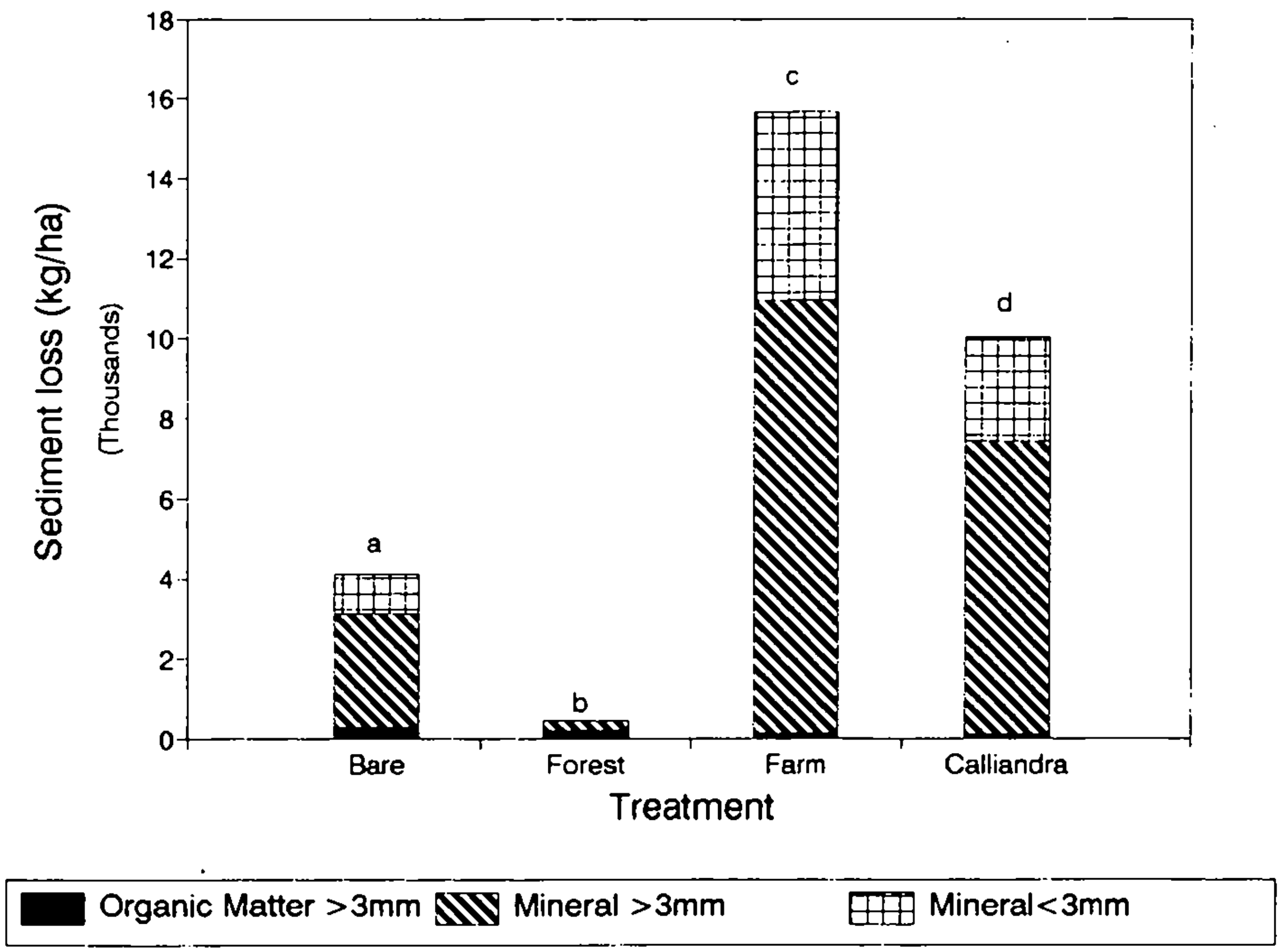


Figure 15 Cumulative total amounts of eroded material lost from plots per unit area during the first year after treatment



Chapter 4

Is there a role for agroforestry in smallholder farming systems in the Blue Mountains of Jamaica?

MSc dissertation, University of Edinburgh, pp 77

Mark Aldrich

Smallholder farming in the Blue Mountains of Jamaica has resulted in all but the highest slopes being cleared of forest cover. The absence of soil conservation measures on the steep slopes, combined with the use of uncontrolled burning and periods of intense seasonal rainfall, has led to very high rates of soil erosion, meaning that present farming practices are unsustainable. Siltation has led to further problems downstream, such as periodic flooding, water supply problems and offshore damage to coral reefs and other marine life.

The introduction to this study describes how control of these soil erosion and land degradation problems is complex, and must incorporate cultural, socio-economic and institutional considerations along with physical and technical solutions. Past soil conservation attempts in Jamaica have had little success despite awareness of the problems and potential solutions, with insufficient funding to the relevant government sector often quoted as the most likely cause.

In a new approach, current research in the Upper Yallahs Valley is investigating the potential of agroforestry, particularly contour hedgerows, for soil conservation. This case study was designed to complement such work, and starts with a description of the study area, followed by an outline of three recent planning developments which suggest that funding for soil conservation programmes may become available in the near future.

Prior to the implementation of such projects, considerable further background work is required. In order to gain information regarding cultural, socio-economic and institutional issues from past experience, a review of past survey work, project evaluation and information gained from discussions with local farmers is presented.

This study concludes that agroforestry does have a very important part to play in smallholder farming systems in the Blue Mountains of Jamaica. However, in order to be effective it must be incorporated into long-term integrated land management plans. For such planning to be suitable for the range of conditions, both physical and socio-economic, and for the resources available in a particular area, any lessons gained from past experience must not be overlooked. To date there appears to have been an absence of any previous work which brings all the existing information regarding the Upper Yallahs Valley together into one document. This study was designed to help meet this need. In addition, the ideas and opinions of the local population should be taken into consideration and their on-going participation must be encouraged in the process of planning and implementation.

The main recommendations are as follows:

1. Planning should be carried out with a long-term perspective, using a basic framework which develops from a small-scale intervention, through a building phase, to a fully integrated project.

2. A diagnostic survey using a relaxed and participatory approach should be carried out to obtain background information about the current situation.

3. A series of demonstration plots and on-farm trials should be established, and managed by researchers and farmers in partnership, so that a range of ideas can be tested and adapted, thus increasing the chances of adoption. Consideration needs to be given to what timetable would be realistic, labour requirements and economics, mutual participation and experience in other countries, especially the Slopping Agricultural Land Technology system in the Philippines.

4. Land and tree tenure issues must be carefully considered. Again experience in other countries must be carefully considered.

5. Future extension programmes should be developed from the small-scale efforts already made. The approach, both in terms of design and management control must be carefully planned.

6. A full project appraisal and cost-benefit analysis should be carried out in order to consider the potential impacts of project implementation. The inclusion of environmental and social benefits into an economic analysis may help to justify the project on economic grounds.

Further detailed recommendations are made about each stage of this process in the main report of this study.

Mr Aldrich has also written the following other related working-papers:

1. An extension programme for the Upper Yallahs Valley, Jamaica.

2. A small-holder farming system in the Blue Mountains, Jamaica.

3. Appraisal of a project to introduce an agroforestry buffer zone management scheme to the Blue Mountains National Park.

Chapter 5

A socio-economic survey into the effects of soil and water conservation measures on farming and family systems

M A McDonald, M J P M Riksen, J W C Versteeg, J de Graaff & J R Healey

A socio-economic survey into the effects of soil and water conservation measures on farming and family systems has recently been carried out by M J P M Riksen and J W C Versteeg of the Department of Irrigation and Soil Water Conservation of Wageningen Agricultural University, as part of a larger international study led by Dr J de Graaff of the same Department. They surveyed 58 farmers in all of the major watersheds surrounding Kingston: the Yallahs, Hope and Wagwater Rivers and the Rio Cobre.

The socio-economic survey that has been carried out by Riksen and Versteeg yielded very useful information on the socio-economic status of hillside farmers in the watersheds surrounding Kingston. However, the farmers surveyed operated in the lower portions of the watersheds, and did not include the more marginalised farming population in the upper parts of the watersheds. Therefore, we have initiated a project to extend this survey into the Upper Yallahs watershed. The questionnaire that we are using is shown in the Appendix. Interviews began in October, 1993, and to date, five farmers have responded. A total of 30 farmers will be interviewed and the data presented in the final report.

Chapter 6

Nutrient Cycling and Soil Formation in Young Secondary and Primary or Old Secondary Forest

BSc dissertation, University of Calgary, Canada

S Morin

The forest studied in the main project (Chapter 3) is secondary, which is, of course, highly relevant to current land-use issues in the region because it is this type of forest which is being actively cleared for food crop agriculture and coffee plantations. However, considerable erosion may generally occur after the initial clearance of the forest, and hence lower rates of erosion will be encountered with subsequent clearances. It was to test this hypothesis that we carried out a comparative study of the degree of soil formation (from the soil profiles) and organic matter inputs between young secondary and old secondary or primary forest.

The study was conducted in August/September 1992 in young secondary forest that had been disturbed within the last 30 years and older secondary or relatively undisturbed forest which had probably suffered no significant disturbance within the past 150 years (hereafter referred to as primary). The disturbance histories of the forests concerned were investigated by using a combination of local knowledge and species composition and size.

Three locations were selected where stands of primary and secondary forest were in close proximity on the same aspect and slope. A 15 m x 15 m plot was established at each site (six in total) and the species composition and basal areas were recorded for each plot. Four soil pedons (pits) were dug in each plot (24 in total). Full soil profiles were described for each pedon, analyses of pH, conductivity and particle size were carried out and lime requirement estimated. There were problems in getting the chemical analyses done at the University of Calgary, but total nutrient contents may be analysed for this winter. Ten litter traps of 1 m^2 were placed in each plot, and emptied every three months over a period of one year. The samples were dried and will be sorted into leaves, small woody litter and reproductive structures. These samples will be weighed and the components analysed for N and C content as an index of litter quality.

Initial analysis of the soil data indicates that the horizons were generally the same for all sites and only varied in depth and chemical properties (Table 2). Horizon depth was highly variable - all plots had an Ah horizon and two B horizons separated by the degree of weathering. B1, and generally B2, horizons displayed full soil development, while B3 horizons (if they existed) were often unconsolidated bedrock.

TABLE 2 Characteristics of soil in each horizon in secondary and primary forests in the Blue Mountains, Jamaica

	pH	Cond.	% Sand	% Clay	% Silt
Site 1 Secondary					
Ah	5.42		67	10	23
B1	5.38	41.7	64	15	20
B2	5.91	16.3	70	15	15
B3	6.05		64	12	24
Site 1 Primary					
Ah	5.19	65.4	78	10	11
Bh			58	23	19
B1	5.44	26.6	76	9	14
B2	5.65	14.8	82	12	5
B3	6.07	11.0			
Site 2 Secondary					
Ah	5.33	0.8	64	20	16
B1	5.17	41.8	62	16	22
Site 2 Primary					
Ah	5.72	78.6	48	20	22
B1	5.31	37.0	44	29	26
B2	5.79	19.4	53	18	29
B3	5.56				
Site 3 Secondary					
Ah	4.47	58.8	64	12	24
B1	4.68	23.2	45	30	25
B2	5.20		47	25	28
Site 3 Primary					
Ah	4.82	296.0	55	20	24
B1	5.22	61.7	41	36	23
B2	5.16		47	25	28

A full analysis of these soil data, and the data of species composition and litter input will be presented in the final report.

Chapter 7

Fourteen years of regeneration in a cut gap in tropical montane rain forest in Jamaica

MSc dissertation, University of Wales, Bangor, pp 90

Kemonna K Keapoletswe

There is a paucity of quantitative information on the rate of recovery of montane tropical forests from human disturbance either in terms of the rate of increase of biomass or of species diversity. This information is vital for the development of scientifically based management of such forests to meet the multiple objectives of protecting catchments, biodiversity and the needs of local people for forest products. In the context of the protected, National Park status of the forests in the Blue Mountains of Jamaica, this will centre on the management of the use of the forest by local people rather than any commercial scale forestry operations. It is important to be able to assess the length of time taken for the forest to recover to its original biomass, so that the time-span needed for any cycle of repeated cutting of the forest to be sustainable can be assessed. In protected areas of high conservation status, it is also vital to assess the extent to which the species diversity of the forest recovers after the cutting. These considerations would apply both to cutting of the forest for extraction of timber and fuel-wood and to clearance of the forest for shifting cultivation.

The main part of this project (chapter 3) is designed to investigate the impact of shifting cultivation on the catchment protection role of the Jamaican montane forests. In this case, attention focuses on the effect of the cultivation period (with much of the soil surface being bare and disturbed) on the protection of soil and water resources. In contrast, the simple cutting of forest for extraction of wood tends to occur in smaller patches at higher altitudes and there is no prolonged period of exposure of bare soil. It was the recovery of the forest from such disturbance that the study in this chapter was designed to investigate.

This study describes the growth and population biology of stems of individual species recruited from seed and basal sprouting in a 10 x 10 m experimental plot set up to investigate the components of biomass and canopy recovery following clear cutting in a tropical montane rain forest in Jamaica. A method of predicting stem and leaf dry weight from stem volume was used to estimate stem and leaf dry weight of standing trees in the plot between 1985 and 1991.

Following clear-cutting of the plot in 1977 the total above-ground biomass of stems harvested from sub-plots in 1979, 1982 & 1985 were 358 g m^{-2}, 2008 g m^{-2} & 2345 g m^{-2}. Estimated total above-ground biomass of standing stems $\geq$ 3 m tall in 1985, 1987, 1989 & 1991 were 1661, 2363, 3212, & 4711 g m^{-2} respectively. The percentage contribution of coppice shoots to the total above-ground biomass in each of the above enumerations was respectively 10.6, 7.5, 6.3% & 6.3 % in 1985, 1987, 1989 & 1991.

The rate of biomass increase of harvested stems from 1977 to 1979, 1982, and 1985 was 172 g m^{-2} yr^{-1}, 402 g m^{-2} yr^{-1} and 293 g m^{-2} yr^{-1}, and of enumerated stems from 1977 to 1985, 1987, 1989 and 1991 was 206, 240, 265 and 346 g m^{-2} yr^{-1} respectively. The average rate of biomass increase of the above four enumerations is 264 g m^{-2} yr^{-1}. Total above-ground biomass in 1985, 1987, 1989 and 1991 was 5.0, 7.1, 9.7 and 14.3% respectively of the mature forest which occupied the site before clear cutting (33 kg m^{-2}). These figures reflect the low rate of biomass accumulation in tropical montane rainforests compared to nutrient-rich lowland tropical rainforests, and it is estimated that it will take about 125 years before the stand reaches its original biomass.

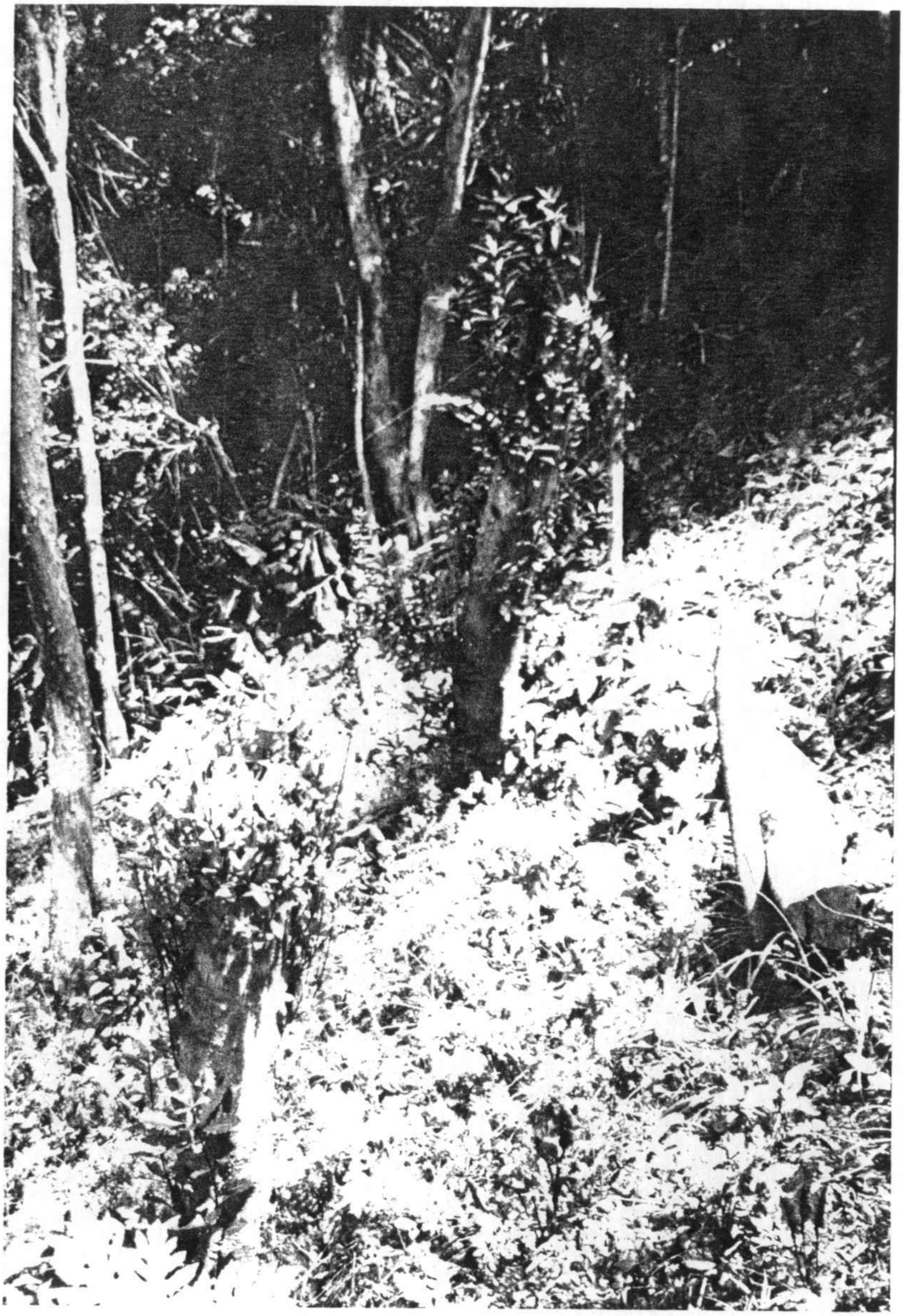
Twenty six tree species with stems greater than or equal to 3 m tall were recorded in the study plot between 1985 and 1991. The total number of tree species at each enumeration was 23, 21, 17 and 23 and there were 172, 155, 121 and 138 individual stems respectively. The four most important tree species during the study period were *Pittosporum undulatum, Eupatorium critoniforme*, *Brunellia comocladiifolia* and *Eupatorium parviflorum*. These species comprised over 67% of the relative density, over 80% of the relative dominance (basal area), and over 84% of the total dry weight at each of the four enumerations. *P. undulatum* was the most dominant species in terms of every index.

Species recruited from seed germination showed higher rates of recruitment and mortality than species recruited primarily from coppice shoots. Mean height and diameter at 30 cm of seed-origin stems was higher than of coppice shoots in all the enumerations. *B. comocladiifolia* and *Miconia dodecandra* had the highest height and diameter growth rates in the study plot. We predict that the dominance of *P. undulatum* will reduce species diversity in disturbed sites in well-developed Mull Ridge Forest.

The major applied implications of this study are as follows:

1. The low recovery rates of the forest biomass indicates that the existing natural forest will not support intensive harvesting. The projected time period required for the forest to recover to its original biomass (125 years) indicates the minimum return period possible for a harvesting cycle. Repeated disturbance of the forest within that time period might well lead to more severe longer-term degradation.
2. The rate of recovery of the tree species diversity of the forest is very slow. So far, there is no evidence that the cut gap will return to its original tree species diversity. This is probably largely due to the dominance of *Pittosporum undulatum* suppressing the regeneration of native species. Therefore, widespread cutting of the forests in the Blue Mountains is likely to lead to a longer-term loss in biodiversity.
3. Therefore, it is recommend that the Blue Mountains National Park develop alternative strategies for satisfying the needs of local people for forest products. Disturbance of the remaining natural forest should be kept to an absolute minimum, and any proposals for 'sustainable' extraction of products from the natural forest should be considered extremely carefully. The results of this study provide clear scientific data which can be used by the park management to oppose any unsuitable proposals.
4. Several species showed a good for establishment under very competitive conditions and a good capacity for biomass production. On the basis of this study the following five species are recommended for further consideration in plantation forestry programmes in this region: *Pittosporum undulatum, Eupatorium critoniforme, Brunellia comocladiifolia, Eupatorium parviflorum* and *Miconia dodecandra*.

Plate 12 Re-sprouting cut trees in a plot cleared for shifting cultivation 6 months previously.



Chapter 8

The effects of a hurricane on Jamaican montane rain forests

PhD dissertation, University of Cambridge, pp 287

P J Bellingham

Initial and short-term effects of Hurricane Gilbert on montane rain forests in the Blue Mountains were studied over a period of 3.5 years after it struck. Initial effects were assessed between 5 and 23 months after the hurricane on stems ≥3 cm dbh.

This study demonstrated that a very intense hurricane did not cause great mortality to Jamaican montane forests: initial mortality was low (7.2%) and levels of damage were low compared with other forests affected by hurricanes. In addition, Dalling (1992) showed that relatively little of the forested area in the Blue Mountains was affected by landslides. This study has shown that in the short term, recovery of these forests occurred by a variety of means, including direct recovery by vegetative development, more rapid growth of surviving stems and regeneration by saplings and newly germinated seed. These findings underscore the value of these forests in protecting Jamaican catchments.

Damage to different areas of forest was correlated with their general topographic position, however the correlation was far from absolute and further investigation is needed of the extent to which more sheltered forests are less susceptible to hurricane damage. Forests on the southern slopes and Grand Ridge, which were most exposed to the hurricane, sustained the highest levels of breakage and defoliation. Stems with fresh epicormic sprouts were also more frequent in these areas, but mortality and uprooting could not be linked to topography.

The recovery in the canopy cover of the forests following the hurricane was recorded using hemispherical photographs. These were taken below the forest canopy in four sites between 7 and 33 months after the hurricane. Initially, computed subcanopy PAR was greatest at the site which was most severely defoliated and lowest at the site which was least defoliated. Subcanopy PAR in all sites declined exponentially with time after the hurricane, and there was no difference in subcanopy PAR among the sites by 28 months after the hurricane. These results demonstrate the considerable capacity for recovery (resilience) of the natural forests, even where hurricane damage has been most severe. They indicate that, although Hurricane damage may reduce the value of the forests for catchment protection in the short-term, this capacity quickly recovers.

The resistance and resilience to this hurricane of the most common tree species were determined from an assessment of damage caused by the hurricane, mortality rates, recruitment rates and basal area increments of each species. Two common species (*Cyathea pubescens* and *Mecranium purpurascens*) declined during the hurricane and there was no evidence of their short-term recovery. The other eighteen common species were considered resistant, resilient, or somewhat susceptible and differences among species were related to their regeneration characteristics as seedlings.

The tree species most widely used in reforestation programmes in the Blue Mountains is the introduced conifer *Pinus caribaea*. However, studies of the effect of hurricanes in montane areas of Jamaica (Thompson 1983, Bunce & McLean 1990, Bellingham *et al* 1992, Wunderle, Lodge & Waide 1992) have shown that damage and mortality caused to plantations of this species is much greater than that caused to native montane forests. More reforestation programmes, including agroforestry schemes, are a priority for the area (Government of Jamaica *et al* 1990). These reforestation programmes could potentially utilise native tree species which are better able to withstand the effects of hurricanes than *Pinus caribaea*.

This study showed that some common native tree species survived the hurricane better than others. Of the 20 common tree species examined in detail 7 were found to be resistant to hurricane damage (ranked by pre-hurricane mean basal area increment, these are: *Guarea glabra, Eugenia virgultosa, Maytenus jamaicensis, Clusia havetioides, Bumelia montana, Chaetocarpus globosus* and *Dendropanax pendulus*) and a further 5 somewhat resistant (ranked by pre-hurricane mean basal area increment these are: *Alchomea latifolia, Vaccinium meridionale, Ilex macfadyenii, Cyrilla racemiflora* and *Lyonia octandra*).

These data should be combined with other useful infonnation to produce recommendations for managers attempting to rehabilitate deforested areas of the Blue Mountains of the native species that may be most suitable for tree planting programmes. The first stage should be for trials to be conducted of the most promising species. Based on their resistance to hurricane damage, their growth rates and their natural abundance, the following species are recommended in descending order: *Guarea glabra, Eugenia virgultosa, Maytenus jamaicensis, Alchomea latifolia, Bumelia montana, Vaccinium meridionale* and *Ilex macfadyenii*. *Clethra occidentalis* has been considered suitable for tree planting programmes because of its abundance throughout the Blue Mountains forests and its rapid growth rates in the seedling and sapling phases. However, in this study we found that it does not have rapid growth rates as an adult tree in established forest and it is susceptible to hurricane damage.

Chapter 9

Sprouting of trees in Jamaican montane forests after a hurricane

Journal of Ecology (in press), pp 32

P J Bellingham, E V J Tanner & J R Healey

1. Forests in the Blue Mountains of Jamaica were damaged by Hurricane Gilbert which passed over the island on 12 September 1988.

2. In plots between 1300 - 1900 m recorded 5 - 40 months after the hurricane, most stems (61.4% of 4949 living stems) and most species (44 of 47 common species) had sprouts. Comparing species, the percentage of stems sprouting ranged from 0 - 100%.

3. Broken stems sprouted proportionately more than intact stems; completely defoliated stems sprouted proportionately more than those not completely defoliated; there was no difference between uprooted and upright stems; and stems >10 cm dbh sprouted more frequently and produced more sprouts per stem, than those <10 cm dbh.

4. Eighteen of 28 species maintained a "sprout bank" before the hurricane, and these sprouts grew more rapidly in height after the hurricane.

5. Compared with the average for all species, 5 species sprouted more from below 2.5 m, 8 species more from above 2.5 m and 5 species had sprouts more evenly distributed.

6. Survivorship up to 41 months after the hurricane was higher in stems with sprouts than those without.

7. There was no simple relationship between the frequency of sprouting of species and microenvironments where seed germination and seedling establishment have been recorded. However 8 common species which have rarely been observed to germinate or establish (in a wide range of conditions) had high frequencies of sprouting. We propose that sprouting is an important mechanism by which many species maintain their presence in these forests.

8. Species differed greatly in the percentage of their stems which sprouted, the numbers of sprouts per stem and the height at which they were produced. Species with more than 50% of stems ≤ 10 cm dbh producing resprouts were (in descending order): *Podocarpus urbanii, Lyonia octandra, Cyrilla racemiflora, Eugenia virgultosa, Bumelia montana, Alchornea latifolia, Chaetocarpus globosus, Vaccinium meridionale, Hedyosmum arborescens, Guarea glabra* and *Clethra occidentalis*. This indicates that each of these species may be potentially suitable for coppice production (e.g. in agroforestry systems or woodlots for fuelwood).

Chapter 10

The predictability of the performance of seedlings in a Jamaican montane rainforest

MSc dissertation, University of Wales, Bangor, pp 96

Akogo Mvogo Guillaume

An experiment to investigate the effects of gap creation on forest structure has been conducted in the Blue Mountains of Jamaica since 1985. In this study, data collected in the first four enumerations of the plants initially less than 10 cm in girth at breast height were analysed. The main objective was to evaluate to what extent the performance of individual seedlings can be predicted from measurements of their previous height and height growth rates, and from observations of their local environment and of their leaf number. The first cohort of seedlings (those alive before gap creation) and the second cohort (those that germinated during the first nine months after gap creation) were analysed separately. In addition, the populations of six species were analysed individually to check for any species-specific differences in performance.

In the gap plots, for first cohort seedlings of all species combined in the first cohort absolute growth rate was significantly positively correlated with previous seedling height for heights up to 1.20 m, but not above. The same pattern was observed when individual species were analysed separately. Survivorship was also positively correlated with seedling height. Growth and survivorship were more strongly positively correlated with seedling height over the full height range for seedlings in the second cohort; for all species combined the r^2 values were 87.3% and 70.6% respectively and the correlation was also strong for each species analysed separately. However, relative growth rate was consistently negatively correlated with height. Subsequent growth rates and survivorship were positively correlated with previous growth rates for all but one of the combinations of species and cohorts that were analysed.

There was very little evidence of density dependent control over seedling performance. Some significant correlations were found between sub-plot seedling density and mean seedling height growth rate and survivorship, however, the largest r^2 value was only 11.6%.

It was concluded that, for shade tolerant species, height at the time of gap creation is one of the main predictors of subsequent success. For light-demanding species, it appeared that early germination after gap creation and fast growth were the most important factors controlling success in seedling establishment in gaps. This information is of potential importance for the management of these forests for conservation or the production of particular species. It indicates that pre-disturbance regeneration sampling is of potential value for determining which species will regenerate successfully after natural or human disturbance. During this sampling the relative heights of seedlings and saplings of the different species must be recorded. In addition, post-disturbance sampling will also be required for the more light-demanding species; this sampling could be carried out within the first 18 months of the disturbance, before the vegetation has grown up so much as to make access difficult.

Conclusions

The major conclusions of the study are given in Section 1 (Introduction, objectives and achievements in 1993). In the conclusions here are two sections, firstly an overview of the potential role of agroforestry for improvement in the sustainability of agriculture in the upper catchments of the Blue Mountains, and secondly a preliminary assessment of the most suitable native tree species for tree planting programmes in different environments in this area.

1. Hedgerow intercropping: a potential agroforestry system for hillslope agriculture

Recommendations for any agroforestry system in this area must take account of local environmental, social and marketing factors to result in activities appropriate for the locality. Too often in the past, similar projects have failed to take advantage of the enormous value of the knowledge held by rural communities and have introduced technologies which were too costly (in time and resources) for the local community to maintain after cessation of the project. They have also underestimated the time that it takes to bring about a change in people's farming practices or failed to provide adequate demonstrations of technologies. Subsistence farmers have learned from bitter experience to be cautious about introducing change - they have neither the time nor the resources to take risks, and hence tend to be very conservative.

Hedgerow intercropping is a simple technique which has the potential to exist on fairly meagre resources, and to build gradually upon local initiatives, while depending on local knowledge, technology and labour. The technique involves the growing of hedgerows of trees, or a perennial crop, as a barrier along the contours of a slope, with the areas between the hedges being used for agricultural production. Most hedgerows have been established with a single species, the desirable characteristics of which include a supply of viable seed, vigour, fast growth, nitrogen fixation, copious biomass and useful by-products. On steep slopes, one of the principal reasons for hedgerows is erosion control; and in those places the by-products might be of secondary importance, except to the farmer (Pellek, 1992). The plots within this project have been established on slopes of, on average, 20-30°. There are a few examples of the use of hedgerows for soil conservation on slopes of this steepness, most notably in the Philippines (Agustin and Nortcliff, unpublished data) and Haiti, and there is an urgent need for more research into a variety of agro-ecological conditions.

The advantages of hedgerow intercropping over traditional crop arrangements are potentially multitudinous and are summarised by Pellek (1992) as follows:

a) Water relations

Perennial crops with deep root systems increase the depth of surface water penetration via root channels or by breaking up hardpans. Transpiration rates of perennial plants increase the overall humidity in the crop canopy, which is also enhanced by shelter, thus reducing transpiration rate and increasing water use efficiency of the annual plants. Water cycling efficiency is improved because of sub-soil water accessed by the deeper-rooting perennial plants.

b) Plant relations

The root systems and litter inputs from perennial crops improve soil structure, organic matter content, water-holding capacity and hence soil fertility. The deeper roots access sub-soil nutrients and improve nutrient cycling, and green manuring with the nitrogen-rich biomass will improve fertility and soil conditions throughout the farmed area.

c) Environmental effects

Contour barriers help to dissipate the energy in the overland flow of water, lessening the risk of erosion (in major storms this effect may be slight). As they mature and grow in diameter, the trees become more effective at reducing erosion and become more productive, and as the soil accumulates upslope of the trees and increases the potential for water infiltration, they become even more efficient.

d) Economic factors

Hedgerows can be quick and inexpensive to establish through direct seeding of some species by a single farmer using seeds that may be available on the farm; they require little maintenance; the hedges can be a source of fodder, green manure, fuel and other material, and can be designed to produce fruit and other edible crops for human consumption. Income can be derived directly from hedgerow crops, and/or indirectly from savings in fertilisers by green manuring or in fodder for animals.

e) Choice of species

In this area, *Calliandra calothyrsus* is potentially a very suitable species for a hedgerow intercropping system (Thompson, 1986; MacQueen, 1992) and has been identified as having potential for fuelwood production in the National Park buffer zone (Kerr *et al*, 1991). It is recognised as having global potential for the rehabilitation of degraded forest and abandoned agricultural land (NRC, 1983). The species is very popular with the local farmers, nitrogen-fixing, fast-growing, produces large quantities of nitrogen-rich litter and dense fuelwood, coppices well after one year and branches close to the ground (and is therefore good for soil protection). In addition, it could be a valuable fodder source for livestock towards the end of the dry season when other sources are becoming scarce - it is precisely at this time that the trees should be cut back to capitalise on the forthcoming rains.

2. A preliminary assessment of the most suitable native tree species for tree planting programmes in different environments in the upper catchments of the Blue Mountains

The studies of the ecology of the native tree species which we have carried out have yielded information that is valuable for the selection of species for forestry and agroforestry programmes. Below is a preliminary list compiled from the data of each of the separate studies. This list will be updated in the final project report. It is clear that a large number of native tree species are potentially suitable. This would allow tree planting to be used to create forests (or agroecosystems) with a high biodiversity

2.1 Fire-resistant species for areas outside forest zone

a) extremely fire-resistant species suitable for areas subject to frequent fires:

Dodonaea viscosa var. *angustifolia*
Baccharis scoparia

b) species that are moderately fire-resistant once established; suitable for areas at risk of infrequent fires:

Clethra occidentalis
Vaccinium meridionale

2.2 Species suitable for general tree planting purposes (where site conditions are not too severe)

They have a combination of widespread distribution, reasonable growth, hurricane-resistance and sprouting ability:

Alchornea latifolia (its seedlings are abundant colonisers of forest gaps and are fast-growing, its adults are fast-growing and sprout vigorously but only partly hurricane-resistant)
Bumelia montana,
Vaccinium meridionale and
Ilex macfadyenii (all three are widespread and moderately abundant, very or somewhat hurricane-resistant, sprout frequently and produce sprouts of moderately vigorous growth. However, the seedlings of *V. meridionale* and *I. macfadyenii* are quite rare)
Guarea glabra and
Eugenia virgultosa (they are both very shade-tolerant and may be hard to establish in open dry sites; also they may be too slow-growing as seedlings to become established above weeds in open sites. *E. virgultosa* sprouts well (but produces large numbers of small sprouts), *G. glabra* sprouts moderately well)
Maytenus jamaicensis (it is rare in southern slope forest and sprouts very infrequently).

2.3 Species suitable for establishment of tree cover in moist sites where competition with herbaceous weeds is a severe problem

They are early successional species whose occurrence is naturally associated with disturbance. However, they are generally not found in open dry areas so they may not be suitable as for the initial establishment of tree cover on completely bare sites.

a) Fast-growing light-wooded pioneers:

- tall trees:
Brunellia comocladiifolia
Miconia dodecandra
Trema floridanum

- shrubby trees:
Heterotrcihon umbellatum
Bocconia frutescnes

b) Later successional species (they also can be early colonisers, but are more shade-tolerant):

- trees:
Eupatorium critoniforme
Eupatorium parviflorum.
Miconia theazans,
Miconia quadrangularis,

- shrub:
Palicourea alpina

2.4 Species which may be suitable for planting on landslides

These are amongst the few tree species whose seedlings are found naturally colonising landslides; they are arranged in rank of importance value on landslides (Dalling 1992)

Clethra occidentalis
Vaccinium meridionale
Lyonia octandra
Podocarpus urbanii
Cyrilla racemiflora

2.5 Potentially useful species that require further investigation of their suitability

a) Species abundant in southern slope forests:

Myrica cerifera (could be nitrogen-fixing; common at forest margins, young trees are common on old landslides)
Garrya fadyenii
Citherexylum caudatum

Viburnum alpinum and *Viburnum villosum*
Daphnopsis americana subsp. *cumingii*
Acalypha virgata var. *virgata* (shrubby, moister sites)
Picramnia antidesma (in moister sites)

b) Tree species with a wider, more scattered distribution:

Ocotea patens (*Nectandra patens*) (sprouts well)
Persea alpigena (sprouts well)
Cinnamomum montanum (sprouts well)
Laplacea haematoxylon
Rhamnus sphaerospermus
Ilex species, *I. harrisii* etc. (probably all slow-growing)
Myrsine coriacea (fast-growing, at least when young)
Symplocos octopetala

c) Abundant tree species:

Clethra occidentalis (although extremely abundant and widespread as an adult it is not fast-growing. Its seedlings are rare inside the forest but are fast-growing and it is the most abundant species colonising landslides, therefore it may be very suitable for reforestation of these sites (see 4 above). Adults are somewhat hurricane-susceptible and sprout only moderately frequently.)

2.6 Species which appear to be unsuitable

a) Probably unsuitable for general tree planting:

Lyonia octandra and
Cyrilla racemiflora (both are widespread in primary and secondary forest, are somewhat hurricane-resistant and sprout well. Their seedlings are amongst the few species to be found on landslides, therefore they may be suitable for reforestation of such severely disturbed sites (see 4 above). However, their use for forestry programmes is restricted because they are very slow-growing.)
Turpinia occidentalis (it is fast-growing but somewhat hurricane-susceptible and suffers severe defoliation as a seedling.)
Myrtaceae species (they are probably all too slow-growing, but *Eugenia virgultosa* is so abundant and hurricane-resistant that it is recommended for further consideration, see 2 above.)
Chaetocarpus globosus (it is hurricane-resistant and sprouts frequently, but it is not abundant in the forest as an adult and its seedlings are very rare; it is slow-growing.)

b) Unsuitable for tree planting:

Haenianthus incrassatus and
Solanum punctulatum (their distribution is very patchy, their seedlings are vulnerable to predation and physical damage and are hard to establish, they probably have little seed dormancy)
Podocarpus urbanii (a high proportion of trees produce sprouts, but the sprouts have poor survival. It is hurricane-susceptible; its seedlings are found at a low density on landslides)
Dendropanax species (they are too hurricane-susceptible and too slow-growing)
Hedyosmum arborescens (it is hurricane-susceptible - it is very weak-wooded and suffered high mortality, but those trees which survived showed very rapid sprout growth - its seedlings were recruited in large numbers after the hurricane and its adults are fast-growing)
Meriania purpurea and
Mecranium purpurascens (they are hurricane-susceptible, their adults have only a localised distribution and their seedlings are extremely rare)
Clusia havetioides (hemiepiphytic)

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Dissemination and extension in 1993

1. *Refereed journal papers*

1.1. Bellingham PJ, Tanner EV & Healey JR (1993) Sprouting of trees in Jamaican montane forests after a hurricane. Journal of Ecology (in press). 32pp.

1.2. McDonald MA, Healey JR & Devi Prasad PV (1992) The effects of forest clearance on soil conservation: preliminary findings from the Yallahs Valley, Jamaican Blue Mountains. Caribbean Geography, 3, 253-260 (published in 1993).

2. *Books and monographs*

2.1. Bellingham PJ (1993) The effects of a hurricane on Jamaican montane rain forests. PhD thesis, University of Cambridge. 288pp.

2.2. Akogo Mvogo G (1993) The predictability of the performance of seedlings in a Jamaican montane rain forest. MSc thesis, University of Wales. 96pp.

2.3. Aldrich M (1993) Is there a role for agroforestry in smallholder farming systems in the Blue Mountains of Jamaica? MSc thesis, University of Edinburgh. 77pp.

2.4. Keapoletswe KK (1993) Fourteen years of regeneration in a cut gap in tropical montane rain forest in Jamaica. MSc thesis, University of Wales. 90pp.

2.5. Morin S (1993) Nutrient cycling and soil formation in young secondary and primary or old secondary forest. BSc thesis, University of Calgary.

3. *Reports*

A 54-page annual report was completed and copies of it were distributed to relevant government departments and NGOs in Jamaica, the UK and elsewhere.

4. *Other*

4.1. In May, the project staff took a television crew to the project's field sites, together with a party of UWI students, to make a ten minute programme for Jamaican national television. The filming included a detailed examination of the work of the project and interviews with our partner farmers.

4.2. Project staff have taught in the new final year BSc unit in "Applied ecology, agroforestry and sustainable development" at the University of West Indies, Mona. This teaching drew extensively on the project's research work and the students undertook two field-trips to the project sites.

4.3. Project staff held meetings with various senior members of staff of Jamaican government departments, the private sector and NGOs in order to discuss with them the achievements of the project to date and our future plans. Close liaison has continued with the local farming community. The agroforestry plots within this project have encouraged participation by demonstration, and project staff have assisted a number of local farmers to plant trees on their farms.

Objectives for 1994

1. Objectives up to June 1994 under the current project funding:

1.1. To continue to measure the main experimental plots for a further three months.

1.2. To complete the socio-economic survey.

1.3. To analyse all the scientific and socio-economic data.

1.4. To produce dissemination material in the form of: refereed papers; a report giving recommendations for future strategic agroforestry research; a technical report for use in the Caribbean summarising the scientific and socio-economic results and their applications implications; extension materials for use in the farming communities of the Blue Mountain region.

2. Objectives up to December 1994 should a project extension be granted:

These objectives are presented in detail in the project extension application; they are summarised here.

2.1. To continue to measure the main experimental plots until September 1994 (two years after the start of the experiment). This would allow conclusive answers to be obtained to the major questions which the study is designed to address. The plots would be maintained for periodic measurements after that.

2.2. To carry out a sufficiently well sampled socio-economic survey of the local farming community to allow full-cost benefit analysis of agroforestry and other soil conservation techniques.

2.3. To select the vegetative techniques and species best suited for soil erosion control in the Caribbean uplands in collaboration with Dr Jane Clark (Natural Resources Institute, Chatham). We have already installed some preliminary trials to screen woody species for their suitability for slope stabilisation and control. The objective is to determine whether species could be propagated from horizontal truncheon cuttings, and hence be suitable, as easily generated material, for erosion control structures in bio-engineering programmes. Fascine bundles of *Pittosporum undulatum, Paraserianthes lopantha, Calliandra calothyrsus* and *Alchomea latifolia* (a native species) have been established at a high elevation site near Cinchona. Bundles of *Albizia lebbeck, Gliricidia sepium* and *Bursera simaruba* (native) have been established at a lower elevation site near Kingston. These bundles will be dug up and examined for their rooting depth and characteristics and resprouting ability.

2.4. To actively promote the use of the applied recommendations resulting from the research into catchment protection, both in terms of control of deforestation and the adoption of appropriate agroforestry and other soil conservation techniques. This would take the form of the establishment of demonstration plots, a technical manual and extension leaflets, radio and television programmes and the materials for a regional workshop to be held in February 1995.

2.5. To actively promote the use of the research results into the impact of Hurricane Gilbert on the forests of the Blue Mountains by foresters and land-use planners. We will produce a technical report which will identify the resistance and resilience of different forest types and tree species to hurricane impact. We will also produce a large-scale map of the Blue Mountains, GIS files and an accompanying report detailing the degree of correlation of long-term risk of damage from hurricanes with each component of site type (topographical position, soil type, hydrological zone etc).

Appendix

Questionnaire form for socio-economic survey into the effects of soil and water conservation measures

Department of Irrigation and Soil and Water Conservation
Study on economic analysis of soil conservation & watershed development (Kingston watersheds)

SURVEY FORM

Interviewer : ....
Date : ....
Form Number : ......
Watershed : ....

1. IDENTIFICATION

Name of head of household ....
Address ...., ...
....
Address farm ...., ...
....
Participating in (project) ....

Farmer status ... (1= Full time 2= Part time)

2. FAMILY, HOUSEHOLD AND LABOUR SITUATION

Family size; ..... persons ...... male ...... female

	Head		Other members of household					
No	1	2	3	4	5	6	7	8
Sex	M	F	...	...	...	...	...	...
Age	...	...	...	...	...	...	...	...
Education	...	...	...	...	...	...	...	...

(Education code; 1=none 2=primary/all-age level 3=secondary/technical level 4=tertiary level 5=university 6=other)

Work outside own farm, including migration (July '92 - June '93)

Are or have been there any members of the household working outside the own farm? If yes who, when, how many days, what kind of work, where and earnings.

....
....
....
....
....

Are there other persons, not belonging to household, who work regularly on your farm? If yes how many Males, Females, age, when, how many days, what kind of work, where and earnings. ....

....
....
....

....

3. Information about assets

	Estimated total value (J$)
Buildings	....
Barns or stables	....
Tractor	....
Farm machinery	....
Spraying equipment	....
Small equipment	....
Other	....

4. Information about socio-economic status

Do you have:

Car	Y / N	Draugh animals	Y / N	Refrigeratcr	Y / N
Motorcycle	Y / N	Electricity	Y / N	Radio	Y / N
Bicycle	Y / N	Generator	Y / N	Television	Y / N

Type of house: .... No. rooms: .....

Ownership ...... (Ownership codes; 1=own 2=rent 3=family 4=other)

Water supply: ....

5. Household consumption

Average consumption

Can you give a description of the daily household consumption (what and amounts and bought [b] or own farm products [o])? ....

....

....

....

....

....

....

What are approximately your household consumption expenditures for one week?

.... J$

Other expenditures (J$)		amount		unit
Rent		....	a	....
Transport		±............	a	....
Medication		±............	a	....
School		....	a	....
Electricity		....	a	....
Water		....	a	....
Others	....	....	a	....
	....	....	a	....

Are you able to provide your family in their needs? Yes / No . If No what is lacking ....
....
The reason: ....
....
....
....

6. LIVESTOCK

Category	1 Cattle	2 Pigs	3 Goats	4 Donkeys/Mules	5 Chicken	6 Other
Total number	....	....	....	....	....	....
Adult female	....	....	....	....	....	....
Adult male	....	....	....	....	....	....
Young female	....	....	....	....	....	....
Young male	....	....	....	....	....	....
Changes in past year						
Birth	....	....	....	....	....	....
Death	....	....	....	....	....	....
Home consumption	...	....	....	....	....	....
Bought	....	....	....	....	....	....
Total cost(J$)	....	....	....	....	....	....
Sold	....	....	....	....	....	....
Tot. value(J$)	....	....	....	....	....	....
Production						
Product I	....	....	....	....	....	....

(Product codes 1=milk, 2=eggs, 3=manure, 4=labour [hire out] 5=other)

fill in unit	....	....	....	....	....	....
Production	....	....	....	....	....	....
Price: J$/unit	....	....	....	....	....	....
Product II	....	....	....	....	....	....
fill in unit	....	....	....	....	....	....
Production	....	....	....	....	....	....
Price: J$/unit	....	....	....	....	....	....

Inputs (J$)	Cattle	Pigs	Goats	Donkeys/Mules	Chicken	Other
Fodder	....	....	....	....	....	....
Concentrates	....	....	....	....	....	....
Other	....	....	....	....	....	....

7. INFORMATION ABOUT LAND

Draw a map of the farmland at the bottom of the last page and number the parcels. Use these parcel numbers for the rest of the questions.

No of parcel	1	2	3	4	5	6	7
Type of land	...	...	...	...	...	...	...

(landtype codes: 1=forest 2=foodforest 3=annual/perennial crops 4=Fallow, grassland and ruinate 5=other)

Length(yards/ft)	....	....	....	....	....	....	....
Width (yards/ft)	....	....	....	....	....	....	....
Size (acres)	....	....	....	....	....	....	....
Distance to the farm (chains/mile)	....	....	....	....	....	....	....
Accessibility	...	...	...	...	...	...	...

(Accessibility codes: 1=good 2=fairly good 3= poor)

Ownership	...	...	...	...	...	...	...

(Ownerships codes; 1=own 2=rent 3=lease 4=occupy rent free 5=family land 6=squat 7=rent out/lease out 8=other)

Soil type	...	...	...	...	...	...	...

(Soil codes: 1=clay 2=loam 3=sand)

Soil depth	...	...	...	...	...	...	...

(Soil depth codes: 1= more than 1 ft 2= shallow, less than 1 ft 3=bare rocks)

Slope	...	...	...	...	...	...	...

(Slope codes: 1=Gently sloping, 0^o - 7^o 2=moderate/strongly sloping 7^o-20^o 3=steep 20^o-30^o 4= very steep 30^o-45^o 5=precipitous > 45^o

Erosion (type)	..	..	..	..	..	..	..

(Erosion codes; 1=sheet 2=rill 3=gullies 4=landslide 5=other)

Previous crops 1991/1992

No of parcel		1	2	3	4	5	6	7
Cropping system (1=pure stand 2=mixed)		...	...	...	...	...	...	...
Crop	I	.....	.....	.....	.....	.....	.....	.....
	II	.....	.....	.....	.....	.....	.....	.....
	III	.....	.....	.....	.....	.....	.....	.....

Did you grow the same crop in the past few years (fill in yes or no)

....

(crop codes: 36= Yam 140= Vegetables 250= Citrus 291= Bananas 341= Coffee 342= Cocoa 352= Coconut 8=other, if other fill in name)

8. CROPPING (1992/93)

No of parcel	1	2	3	4	5	6	7
Cropping (1=pure stand 2=mixed)							
system	...	...	...	...	...	...	...
Crop I	.....	.....	.....	.....	.....	.....	.....
Plant distance	.....	.....	.....	.....	.....	.....	.....
Crop II	.....	.....	.....	.....	.....	.....	.....
Plant distance	.....	.....	.....	.....	.....	.....	.....
Crop III	.....	.....	.....	.....	.....	.....	.....
Plant distance	.....	.....	.....	.....	.....	.....	.....
Shadow trees	.....	.....	.....	.....	.....	.....	.....
No trees/plant dis	......	.....	.....	.....	.....	.....	.....

Shadow trees codes: 1=............... 2=............. 3=..............

Production

	1	2	3	4	5	6	7
Amount Crop I	....	....	....	....	....	....	....
Unit	....	....	....	....	....	....	....
Quantity marked	....	....	....	....	....	....	....
Price:J$/unit	....	....	....	....	....	....	....
Quantity live-stock feed	....	....	....	....	....	....	....
Quantity for planting material	....	....	....	....	....	....	....
Quantity home use	....	....	....	....	....	....	....
Amount crop II	....	....	....	....	....	....	....
Unit	....	....	....	....	....	....	....
Quantity marked	....	....	....	....	....	....	....
Price:J$/unit	....	....	....	....	....	....	....
Quantity live-stock feed	....	....	....	....	....	....	....
Quantity for planting material	....	....	....	....	....	....	....
Quantity home use	....	....	....	....	....	....	....
No of parcel	1	2	3	4	5	6	7

No of parcel	1	2	3	4	5	6	7
Amount crop III	....	....	....	....	....	....	....
Unit	....	....	....	....	....	....	....
Quantity marked	....	....	....	....	....	....	....
Price:J$/unit	....	....	....	....	....	....	....
Quantity livestock feed	....	....	....	....	....	....	....
Quantity for planting material	....	....	....	....	....	....	....
Quantity home use	....	....	....	....	....	....	....

What is the reason that you grow these crops?.........................

....

....

Where, to whom do you sell your products? place ....;
distance from this place to the farm (miles) ....;
means of transport ....; type of purchaser ....;
accessibility of the market ....;
why ....

....

Material inputs

No of parcel	1	2	3	4	5	6	7

Seed/planting mat. What type of planting material is used for; (code 1=seed 2=cuttings 3=sucklings 4=seedlings 5=other)

crop I (code)	....	....	....	....	....	....	....
Amount	....	....	....	....	....	....	....
Unit	....	....	....	....	....	....	....
price/unit	....	....	....	....	....	....	....
crop II (code)	....	....	....	....	....	....	....
Amount	....	....	....	....	....	....	....
Unit	....	....	....	....	....	....	....
price/unit	....	....	....	....	....	....	....
crop III (code)	....	....	....	....	....	....	....
Amount	....	....	....	....	....	....	....
Unit	....	....	....	....	....	....	....
price/unit	....	....	....	....	....	....	....

Labour inputs in manhours (F = family labour; HL = hired labour)

No of parcel		1	2	3	4	5	6	7
Crop specific operations								
Planting I	F	...	...	...	...	...	...	...
	HL	...	...	...	...	...	...	...
Planting II	F	...	...	...	...	...	...	...
	HL	...	...	...	...	...	...	...
Planting III	F	...	...	...	...	...	...	...
	HL	...	...	...	...	...	...	...
Reaping I	F	...	...	...	...	...	...	...
	HL	...	...	...	...	...	...	...
Reaping II	F	...	...	...	...	...	...	...
	HL	...	...	...	...	...	...	...
Reaping III	F	...	...	...	...	...	...	...
	HL	...	...	...	...	...	...	...
No of parcel		1	2	3	4	5	6	7

9. EROSION AND SOIL CONSERVATION

What are your major constrains in farming? ....

....

....

Have you noticed any changes in your soil over the years? .... if yes what: ....

....

....

What do you consider as erosion? ....

....

....

....

Do you consider these erosion features as a problem? Yes / No

Why ....

....

....

....

Do you take any measures to minimize the effects of erosion? Yes / No
If yes what kind conservation measure (Conservation measure codes: 1=bench terrace 2=hillside ditch 3=individual basin 4=grass strip 5=barrier (stone or logwood/bamboo) 6=contour cropping 7=other)

No of parcel	1	2	3	4	5	6	7
Conservation measure	...	...	...	...	...	...	...
Year of implementation	....	....	....	....	....	....	....
Costs (J$)	.....	.....	.....	.....	.....	.....	.....
Estimated life	....	....	....	....	....	....	....
Costs of maintenance per year	.....	.....	.....	.....	.....	.....	.....

Assistance in field of agriculture and conservation (1980/93)

Did you get any assistance in field of agriculture and conservation?
Yes / No . If no why not ....

....

If yes;

Kind	...	...	...	...	...	...	...

(kind code 1=planting materials 2=fertilizers 3=subsidies 4=credit 5=other (...)

Year(s)	...	...	...	...	...	...	...
Amount	.....	.....	.....	.....	.....	.....	.....
Value (J$)	.....	.....	.....	.....	.....	.....	.....
No of parcel	1	2	3	4	5	6	7

Are there sufficient means available for the implementation and maintenance of the planned measures? Yes / No If no why, what and how much ....

....

....

....

....

When possible would you be interested in participating in soil conservation projects? Yes / No . Reason: ....

....

....

....

....

Under what condition: ....

....

....

....

....

Assistance in field of agriculture and conservation (1980/93)

Did you get any assistance in field of agriculture and conservation?

Yes / No . If no why not ....

....

If yes; what kind of assistance ....

....

....

....

....

....

Are there sufficient means available for the implementation and maintenance of the planned measures? Yes / No If no, what is lacking ....

....

....

....

....

When possible would you be interested in participating in soil conservation projects? Yes / No . Reason: ....

....

....

....

....

What kind of help would you like to get: ....

....

....

....

....

How do you see the future of your farm? ....

....

....

....

....

FARMERS COMMENTS: ....
....
....
....
....
....
....

INTERVIEWER'S COMMENTS: ....
....
....
....
....
....
....

THANK YOU FOR YOU COOPERATION

MAP OF FARMLAND

(verify whether in ha or acre, and meter or feet)

Size of farmland in this area : = ... ac

Size of farmland in other areas: = ... ac

How much parcels of land do you have in this area? ....