REMOTE SENSING APPLIED TO LAND USE AND EROSION HAZARD STUDIES IN JAMAICA

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SUMMARY

The northern half of the parish of St. Catherine in Jamaica was selected as a test area to study, by means of remote sensing, the problems of soil erosion in a tropical environment.

An initial study was carried out to determine whether eroded land within this environment could be successfully interpreted and mapped from the available 1:25,000 scale aerial photographs. When satisfied that a sufficiently high percentage of the eroded land could be interpreted on the aerial photographs the main study was initiated. This involved interpreting the air photo cover of the study area for identifying and classifying land use and eroded land, and plotting the results on overlays on topographic base maps. These overlays were then composited with data on the soils and slopes of the study area. The areas of different soil type/slope/land use combinations were then measured, as was the area of eroded land for each of these combinations.

This data was then analysed in two ways. The first way involved determining which of the combinations of soil type, slope and land use were most and least eroded and, on the basis of this, to draw up recommendations concerning future land use.

The second analysis was aimed at determining which of the three factors, soil type, slope and land use, was most responsible for determining the rate of erosion. Although it was possible to show that slope was not very significant in determining the rate of erosion, it was much more difficult to separate the effects of land use and soil type. The results do, however, suggest that land use is more significant than soil type in determining the rate of erosion within the study area.

Key Words: Aerial Photography
Soil Erosion
Land Use
Jamaica

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CHAPTER 1

INTRODUCTION

1.1 Background to Study

The research project described in this thesis is part of a continuing programme of research over the last decade involving Dr. W.G. Collins and the Remote Sensing Unit of the University of Aston, in co-operation with the University of the West Indies and various Government Departments in Jamaica.

Over the past fifty years much concern has been expressed with respect to the problem of soil erosion in Jamaica. A number of foreign experts and advisors have visited the island and made recommendations for the implementation of conservation practices. Some Government action has been taken, often with great initial enthusiasm, but inspite of this there has been little or no improvement in the overall position.

It is not within the scope of this research project to detail the reasons for the past failures, which seem to have far more to do with socio-economic and political factors outside the purely agricultural recommendations of the various consultants. It has, however, been necessary to examine the past attempts, at least in terms of their recommendations, since they are, in the main, worthwhile and extremely practical. It was in an attempt to overcome the inertia implicit in the existing system that this project was devised. It was decided that since it has proved extremely difficult to encourage new agricultural techniques and practices, especially in the upland areas of the drainage basins where soil erosion is thought to pose extra problems, it could perhaps be worthwhile attempting to encourage those practices already in use that minimise soil erosion risk while discouraging those that cause the greatest problems. It is appreciated that this is, at best, a stop-gap approach but it is felt that such an approach could be useful in arresting further deterioration in the short term while a long term approach based on education and rural reform is being developed.

The work carried out by Collins (1967) 1972 was directed towards maximising the usage of the available land and, as such, was concerned with identifying that land which, according to the existing land capability classification (Steele, 1954), was being under utilised at the time of photography (1961). It was in an attempt to follow up this work by identifying those areas which, in terms of the land capability classification, were being over utilised, or used for a more intensive form of land use than that recommended, that this research programme was initiated. It was soon realised, however, that this work would be of very little value since it was not entirely clear that the existing land capability classification was an accurate reflection of the true situation on the island. The work of Sheng (1968) appeared to highlight some of the shortcomings of the scheme in use and this led to consideration of an approach which could be independent of the existing classification and could serve as a basis for the development of a new capability classification. The literature review drew attention to the fact that most soil erosion data was based either on test plots or on stream monitoring, very little deriving from field studies. These considerations led to the programme being directed less towards identifying over utilisation of land and more towards quantifying those factors most responsible for determining the rate of erosion and identifying those areas most at risk from future erosion.

Since this was to be an air photo based study it was necessary to be satisfied that all the factors to be quantified could be adequately identified and delineated on the air photos. Soil and slope data were available from the intensive survey carried out by the Imperial College of Tropical Agriculture in the 1950's. Although at a later stage the accuracy of some of the soil data plotting was to be called into question it would not have been practicable to carry out as complete a survey (as that carried out by the Imperial College) within the time span or financial constraints of a PhD research programme.

Sufficient work had previously been carried out in the humid tropics to indicate that land use identification would not pose too many problems. This left soil erosion as the one factor requiring to be mapped from aerial photographs for which relatively little previous work existed to serve as a guide. Sufficient work had been carried out in savanna and semi-arid regions to indicate that it might be possible to identify a high enough proportion of the existing erosion to make the work worthwhile. Soil erosion identification for the purposes of this programme implies the identification of erosion features such as gullies and also the identification of eroded land. Erosion itself is, of course, a process and as such cannot create a photographic image. What is of concern to an interpreter are those products of the erosion process that can be identified on the aerial photograph. Eroded land can normally be identified either because it contains erosional features such as gullies, and/or because the appearance of the surface itself or its vegetal covering has been modified in some way. Chapters 2 and 5 deal with this problem in some detail.

1.2 Selection of Study Area

Having decided upon a general approach to the problem it remained to choose a study area upon which to prove the methodology. Since Dr. W.G. Collins had worked in St. Catherine it seemed logical to continue working in the same area. It was realised, however, that if the whole parish were to be used the differences in rainfall would also become a variable, but that if only the northern half of the parish were to be used the rainfall could be treated as a constant. Additionally the southern half of the parish is composed of limestone uplands of little or no agricultural value and the flat St. Catherine plain, an area of rich alluvial soils, but one requiring irrigation to ensure successful cropping. Neither area is thought to pose an erosion problem and a brief preliminary study of the aerial photographs supported that view. Later, during fieldwork, this area was examined again, but apart from along the incised course of the Rio Cobre little was seen to warrant extending the study to the whole parish.

For a number of reasons it was felt that the study area chosen (see Figure 1.1) was especially suitable as a test area for a methodology which if successful was to be applied to the whole island. Firstly the study area contains most of the rock types to be found on the island and, in consequence, it also contains most of the soil types found on the island. The only major soil types missing from the study area are those developed in marshland and swamps, usually along the coast. Since neither environment is normally associated with soil erosion it was felt that this omission could be safely ignored. Secondly the range of terrain types is broadly representative of those on the island as a whole, although not of course containing anything on the scale of the main range of the Blue

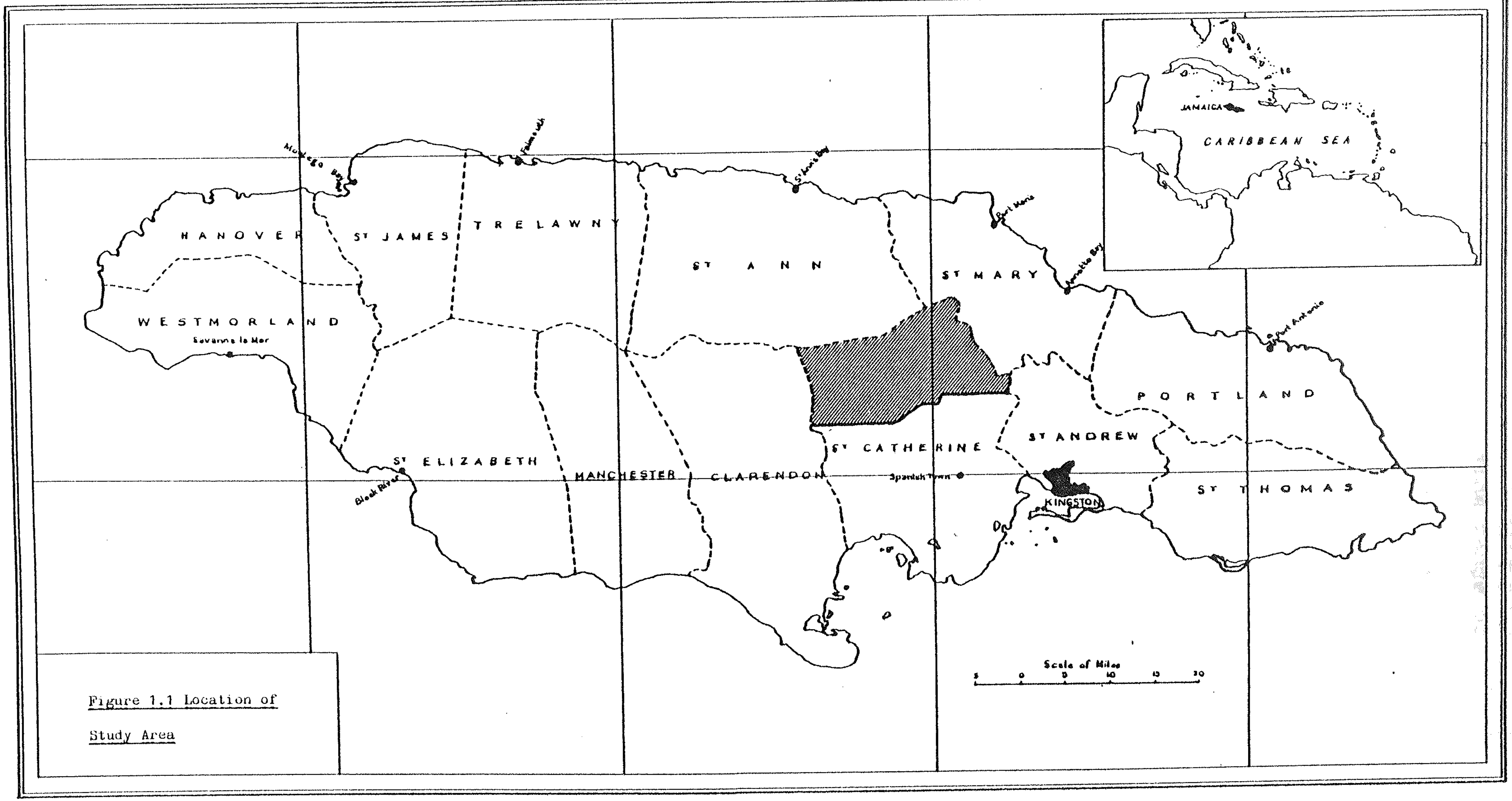


Figure 1.1 Location of Study Area

Mountains. The area does however contain a wide range of slopes; from nearly flat alluvial basins to hilly areas with slopes in excess of 40°. Thirdly the area contains most of the types of agricultural systems found on the island and most of the crops grown except tobacco. There are even substantial areas given over to the cultivation of 'ganja' of marijuana, a major cash crop within the 'Black Economy' that flourishes on the island. The fourth reason for choosing this area is that it has an 'average' erosion problem. The Yallahs Valley and Cristiana have extremely bad problems while St. Elizabeth has relatively few problems, so areas like these would not have been suitable. Whether St. Catherine is actually above or below the average in terms of its total area of eroded can only be determined by measuring that for the whole island, but the feeling with the local Soil Conservation Service was that it would not be very different from the average for the whole island.

1.3 Description of Study Area

Map 1 (rear pocket) shows the main features of the geology of the study area. It can be seen that although the southern limestone upland has been omitted from the study area (see section 1.2 above) there are still extensive areas of limestone within the study area. The area is composed of two interior alluvial basins surrounded by White Limestone uplands. To the north-east and east of the study area and again to the south-west are areas of Cretaceous sediments, igneous and metamorphosed rocks. In these latter areas the succession is frequently interrupted by major faulting along two main axes. One axis runs roughly south-south-east and the other runs roughly east-west. The interior basins are both largely products of these fault systems. Bauxite overlies much of the limestone although the thickness is extremely variable and reaches a commercial depth in the north only.

Map 2 (rear pocket) shows the distribution of the main soil groups within the study area. It should be noted, however, that there are a number of areas where it has not been possible to separate between the soils derived from limestone and those derived from the overlying drift deposits. This is especially the case in much of St. Thomas in the Vale, the larger of the two interior basins. Even at the original field mapping scale of 1:12,500 it was not possible for the soil survey officers to separate them completely. Certain other soils were also grouped together by the soil survey, such as those within the catena formed on the limestone, as a separation would not be practicable. This was to cause certain problems later in the work when the time came to analyse the results. In the main the soil boundaries follow those of the geology fairly closely except in that the pattern within the alluvial areas is more complicated than that indicated by the geological map.

Map 3 (rear pocket) shows the main features of the topography and, in addition, a certain amount of cultural information. This has been added to enable places to be located that are referred to in the text of this thesis.

Topographically the area consists of two interior basins, the larger centred on Linstead at 350 to 400 feet above sea level. The study area comprises the upper part of the Rio Cobre watershed - with the exception of the extreme south-west which forms part of the Mountain River watershed. The main tributaries of the Rio Cobre are the Rio Doro which drains the northern part of the watershed and the Rio Pedro which drains the eastern part. In the upland limestone areas there is an absence of surface drainage, the Rio Cobre sinking underground in Lluidas Vale to reappear about three miles to the east in St. Thomas in the Vale. The interior basins are characterised by gently sloping topography with slopes generally in the range of 0 to 10^{o}, except for along the course of the Rio Cobre which is incised below the general level of both basins. The Rio Doro is also below the general level of the basin but has established a wider flood plain at the lower level and created at least one identifiable terrace. Some of the larger tributaries of the Rio Doro have also formed terraces in their valleys. The limestone areas are characterised by cockpit or doline type topography, although not on the scale of the famous 'Cockpit Country' further west in Trelawny, St. James and northern St. Elizabeth (see figure 1.1). These are steep sided depressions often with slopes in excess of 40^{o} with gently sloping bottoms which can sometimes be cultivated. These are the only parts of the study area where it is possible to see exposures of rock.

The other upland areas on Granodiorite, Andesite or the Cretaceous deposits are generally characterised by steep sided narrow valleys and display a dendritic drainage pattern. Slopes within these areas can often be in excess of 40^{o}, and there is a general shortage of shallower slopes suitable for cultivation. The Granodiorite and Andesite areas tend to be steeper and the valleys narrower than the Cretaceous sediments.

Streams and rivers within the whole study area are characterised by heavy bed loads and an almost complete absence of vegetal development on the bed. When stream flow is low the banks and bed are liberally covered in debris which has been transported from further upstream. During the dry months the Rio Cobre appears dry in the Lluidas Vale but there is, in fact, a substantial flow of water continuing within the sediments that make up the river bed. The Rio Pedro appears to have surface flow throughout the year but the Rio Doro, although marked on maps as having continuous flow, was dry at the time of field work on the island (January to March 1979). It is possible that some flow was continuing within the bed sediments but it was not possible to confirm this.

CHAPTER 2

SOIL EROSION

'The problem remains one of the most serious threatening the future of mankind'. Greenland (1977).

2.1 Introduction

Erosion is a worldwide and natural process the products of which, over the millenia, have given rise to the sedimentary strata that make up so much of the earth's surface geology. Natural erosion is, therefore, a 'healthy' process and like the other processes of the ecosphere should be as little interfered with as possible. The subject of this chapter and this research project is not natural erosion but un-natural, aggravated or man-made erosion. Man's influence upon the process of erosion is, except in coastal erosion, to accelerate the process. This is normally done when he removes the vegetal cover from the soil either by grazing his domestic animals upon it or by removing it to facilitate cultivation. Additional problems are often caused by the engineering work he carries out.

Once the surface covering has been removed, or the soil partially exposed, the rate at which soil erosion will occur is a function of a number of inter-related variables. Among the more important of these are the erodibility of the soil, the erosivity of the rain, the slope (both angle and length) and the degree of protection afforded by whatever remain of vegetal cover. Much work has been done on the problem of soil erosion to try to quantify the rate at which it is taking place, in terms of tonnes/hectare/year or some other convenient units of measurement. Work has also been carried out to determine the major causes of soil erosion and to evaluate the relative effects of the factors affecting the rate of erosion. Until recently much of this work was carried out in the United States because there was both the perception of the problem and the finance to tackle it. Elsewhere although the problem was perceived it received a low priority in finance so little could be done. This is still true of Jamaica where, although the problem was appreciated half a century or more ago, little finance has ever been available either to study the extent of the problem on the island or to adequately fund work on soil conservation. There is also an apparent lack of will to come to terms with the problem since even where legislation exists to control the practices known to contribute to the high rates of erosion on the island there is little or no attempt to enforce that legislation.

The purpose of this chapter is, therefore, to examine the current knowledge of the problem in order to best define how to approach a study of soil erosion in Jamaica using remotely sensed imagery.

2.2 Causes of Soil Erosion

The initial factors affecting the rate of soil erosion are the erosivity of the rain and the erodibility of the soil. Since, however, the initiating factor is the rain it is best to deal with that first.

Much work has been done on determining which factors of rainfall are most closely correlated to the rate of soil erosion. The factors which have been considered include drop size, terminal velocity, kinetic energy, intensity and duration. Work done by Ellison (1944, 1947), Bisal (1950), Rose (1960) ~~etc.~~, seemed to indicate that energy was the decisive factor in determining the erosive power of the rain. It was left to Wischmeier et al (1958) to show that the correlation between soil loss and rain amount was poor, as it was with soil loss and the maximum amount of rain falling in 5, 15 and 30 minutes. Momentum gave a better correlation, but the factor which gave the best correlation was the kinetic energy of the rain. To remove the remaining variation Wischmeier (1958) carried out multiple regressions on all the likely combinations. The best combination was found to be kinetic energy and the 30-minute intensity. The 30-minute intensity is the greatest average intensity experienced in any 30-minute period during the storm. It is determined by using recording rainguage charts to find the greatest amount of rain that falls in any 30 minutes. This amount is then doubled to get the units into inches or mm/hour^{-1}.

This product of kinetic energy and 30-minute intensity gave an excellent correlation. Wischmeier (1958) found that it could be refined still further by adding such factors as initial soil moisture content, but with these minor factors the improvement was so slight that it was felt that it did not justify the added complications.

This measure of erosivity is called the EI_{30} index.

When attempts were made to fit the EI_{30} index to the situation in Africa it was found that the results were not as good as had been expected. The idea arose from the observation that little or no erosion was associated with low intensity rain, that there must be a threshold above which erosion will occur. This then meant that rain at intensities below the threshold could be ignored for the purposes of determining erosivity. The threshold was found, by experiment, to be about

$25mm/hr^{-1}$.

By removing the kinetic energy (KE) of the low intensity rain, and using only that greater than 1"/hr it was found that a good correlation was arrived at. It is used in the same way as the EI^{30} index but is found to give superior results for all tropical and sub-tropical areas. This index is called the KE>1 index.

As with erosivity there have been a number of attempts to evaluate erodibility. Amongst the earliest of these to yield significant data was that of Ekern (1950). He drew up a table (Table 2.1) of material transported by drop impact as influenced by particle size eroded.

TABLE 2.1 Material transport by drop impact (after Ekern, 1950)

Particle	Diameter limits (mm)	Relative Transport (%)
Coarse sand	0.84 - 0.59	30.0
Medium sand	0.42 - 0.25	77.2
Fine sand	0.25 - 0.175	100.0
Very fine sand	0.10 - 0.05	61.0
Silt	0.05 - 0.002	21.0

Fine sand gave the greatest amount of transport while larger particles underwent less erosion by impact. Smaller particles tended to be compacted and the surface sealed. A film of water then developed on the surface which helped to dissipate the energy of the falling drops and this in turn reduced transport. There were other attempts during the 1950's and early 1960's to evaluate the effects of the different factors on the rate of soil erosion. It was not until 1965, when Wischmeier and Smith produced their 'Universal soil-loss equation' that a satisfactory soil-erodibility factor, K, was obtained. This factor was still an empirical factor, obtained by making measurements on test plots under simulated rainfall. Thus, while it was possible to get good values of K for soils tested, it could give only approximate values for soils upon which no tests had been carried out. The values of K could be arrived at only by comparison with tested soils.

In 1969 Wischmeier and Mannering expressed soil erodibility in terms of 15 functions of soil properties. However, this was found to be far too complex for use in the field. Additionally it was found not to hold true where the sand fraction exceded 65 percent, or the clay fraction exceded 35 percent. As a result Wischmeier, Johnson and Cross (1971) produced a nomograph which only used five parameters. These were structure, permiability, percentage silt plus very fine sand, percentage sand and percentage organic matter. The very fine sand was grouped with silt because under normal conditions it was found to act like silt rather than sand.

Work was carried out during this period which used Henin's instability index (reported in Fournier, 1967) in West Africa. This index has three variables, the average percentage of stable aggregates, the dispersed clay and silt fraction and the coarse sand fraction. For the tests themselves account was also taken of permiability.

Despite this and other work carried out since, the Smith and Wischmeier Universal soil-loss equation has remained the normal approach to assessing potential soil erosion. The equation attempts to evaluate all the major factors affecting the rate of soil erosion and not just erosivity and erodibility.

2.3 Other factors affecting the rate of soil erosion

As with erodibility and erosivity much work has been done on the other factors affecting the rate of soil erosion. There is unfortunately not space enough to deal with more than a few of the most important studies.

Zingg (1940) was particularly interested in the effect of slope on the rate of soil erosion. He found that, all else being equal, soil loss varies as the 1.4 power of the percentage slope, and as the 1.6 power of the slope length. Wischmeier and Smith (1962) were to come to a similar result.

Smith (1941) added crop and conservation practice factors to those of Zingg, and Browning et al (1947) added erodibility and management factors.

Musgrave (1947) produced the formula $E = IRS^{1.35}L^{0.35}P_{30}{}^{1.75}$ from data obtained on test plots. In the formula

E = soil loss (acre/in)

I = inherent erodibility of the soil

R = cover factor

S = slope (%)

L = length of slope (feet)

P_{30} = max. 30-minute amount of rainfall, two year frequency (in)

There were further attempts to refine the concepts throughout the 1950's, most of the work being carried out by researchers employed on various agricultural research stations in the United States. Foremost among them was Wischmeier. When, in 1954, the National Runoff and Soil-loss Data Laboratory was established by the U.S. Department of Agriculture at Purdue University, it was possible to gather together more than 8,000 plot years of erosion-plot data from 37 different locations within the United States. This could then serve as the raw material from which Smith and Wischmeier were to construct their 'Universal soil-loss equation'.

The equation is of the form A = RKLSCP

Where;

A = Computed average annual soil loss

R = Erosivity factor

K = Erodibility factor

L = Slope length factor

S = Percentage slope factor

C = Cropping management factor

P = Erosion control practices factor

While the 'Universal soil-loss equation' is useful for commercial agriculture in the United States and perhaps elsewhere, its applicability to other regions and other forms of rural land use still remains to be adequately tested. The same could be said of the other predictive methods based upon multivariate statistical analysis.

The testing and extension of such methods to countries like Jamaica requires independent field measurements of erosion. In Jamaica, as in most developing countries, there is not yet a sufficient body of data upon which to base generalizations like the 'Universal soil-loss equation'. For these purposes it is still necessary to resort to empiricism and to take field measurements of the actual rates of erosion.

Dunne (1977) deals with the two main field approaches to monitoring and assessing soil erosion; that is monitoring sediment yields in a water channel and direct measurements of erosion rates on sample sites.

Both of these approaches are labour intensive, time consuming and costly. Monitoring sediment yield, long the most popular approach since it is easier in operation, has many drawbacks, not least being the difficulty in interpreting what is happening upstream from sediment collected near the outlet from the drainage basin. This would pose no problems if the drainage basin were an homogeneous unit but this is rarely, if ever, the case. Even in an area of uniform soil there will be a variety of slopes and land uses all affecting the rates of soil erosion in different ways.

Where work in the tropics has been done on the ground, and where it has been possible to separate the contributions of the different functions of soil erosion, some interesting results have been obtained with important implications for soil conservation.

Hudson (1977) makes the following points. That we can study rainfall and measure it, but are really unable to significantly modify it. That we cannot sensibly or economically modify the inherant characteristics of the soil and hence its erodibility. That although topography can be modified it may not make economic sense to do so. On this latter point Okigbo and Lal (1977) state the following, 'A majority of the tropical farms, particularly those in South-east Asia and tropical Africa, are below 5 hectares. Commonly recommended practices of terracing, contour farming with adequately designed and properly maintained water ways and cut drains, are neither economically feasible nor practically applicable under the socio-economic and financial resources of the small farmers'.

However, in the area of management there is the possibility to control soil erosion and at a realistic cost. This is because different styles of management can make large quantitative differences in the rate of erosion. Hudson (1977) gives the following approximate values. The variation in the erosivity within a country, or from year to year, might be in the ratio of 5 to 1. The effect of the differences in erodibility might be of a similar ratio; up to 5 to 1. The effect of channel terraces is roughly to halve erosion, i.e. a ratio of 2 to 1. The differences resulting from using different land and crop management techniques could be of the ratio of 1000 to 1.

There is a considerable body of evidence to support this view of Hudson's, much of it provided by his own work at the Henderson Research Institute in the then Southern Rhodesia.

Table 2.2 gives some results obtained by Hudson using mosquito netting to intercept the rain and dissipate its kinetic energy.

<u>TABLE 2.2 Soil Loss and runoff from protected and unprotected soil (after Hudson 1957)</u>.

Mean Annual Values	Bare Ground	Soil Protected with Mosquito-gauge Net.
Soil loss (tonnes/ha/yr)	127	1
Runoff (mm)	271	21
Runoff (% rainfall)	32.2	2.5

Similar results were obtained by Lal (1976) in his work carried out at the International Institute of Tropical Agriculture at Ibadan, Nigeria (Table 2.3).

TABLE 2.3 Effect of Ground Cover on Runoff and Soil Loss for 10% Slope (after Lal, 1976b)

Mean Annual Values	Bare Ground	Mulched
Soil loss (tonnes/ha/yr)	232.6	0.2
Runoff (mm)	504.1	29.3
Runoff (% rainfall)	42.1	2.5

Further examples of the results obtained from various crop and management strategies are given in Appendix A.

What all of this work shows is that if the rain can be intercepted by some form of ground cover, and its kinetic energy removed, then its power to erode is reduced to often insignificant level. There are a number of ways in which to intercept the rain, by using trees, cover crops or mulch. All three methods have their uses, but using trees is perhaps the most limited. There are a number of reasons for this. Firstly, if the tree is quite tall it will often concentrate the rain into big drops which, although not falling very far will still have considerable erosive power. Normally the use of trees is advocated where the crop, such as coffee, requires shade and where the crop will itself provide fairly good ground cover, especially at the critical period at the onset of the rainy period. Williams (1969), on test plots, noted that rainfall of a given momentum caused roughly 20x less erosion in the middle of the wet season when plant cover was 35-40% than at the beginning when the plant cover was only 0-5%. This inspite of both percentage and absolute increases in runoff during the wet season. Alleyne and Percy (1966) observed that pineapples grown on terraces yielded more sediment in the streams than grass with no special anti-erosion measures.

2.4 Effects of Soil Erosion

Although soil erosion has been a continuing problem of semi-arid and Mediterranean type areas almost since the beginning of recorded history, the problem is a relatively new one in the humid tropics. The problem was introduced into the tropics by colonialism by its affects on land use. The initial effect was caused by the colonial power expropriating the best land for the exclusive use of its nationals. This led to the natives, and later the freed slaves, being forced to cultivate the more marginal, often hilly, lands. The second effect was caused by the introduction of 'western' health care, which in many areas led to rapid increases in the population level, which in turn increased pressure on the land.

The effects of soil erosion can be divided roughly into those due to the loss of soil from the site itself, and those resulting lower down in the drainage basin. There are effects which fall outside both of these groups, such as long term climatic changes for which there is evidence in the countries of the Mediterranean and of the Near East.

The erosion may take the form of gullying, with the landscape becoming increasingly dissected, rendering cultivation more difficult in addition to destroying useful land. It may also take the form of sheet erosion.

The initial effect of sheet erosion is to remove the top layer of the soil which is normally the richest in organic material. The surface layer will also be compacted leading to a reduced infiltration rate and increased runoff, which in turn will cause higher soil erosion lower down the slope. This is more of a problem in the tropics, where soils are often shallower with less favourable rooting characteristics in the sub-soil horizon, than temperate zones with their deeper soils. The loss of organic matter in particular is extremely damaging, for, as Baeyens (1938) noted, much of the land occupied by profitable plantations in the lower Congo valley would, if transported to Belgium, be heath or utterly barren moorland. The apparent high fertility of many of the tropical soils depends upon the operation of an almost closed ecosystem which operates at a speed unknown in temperate zones. The high rate of biochemical activity that characterises the tropics is the result of a number of factors, among them the high rate of supply on the ground of organic material caused by the density of the vegetation, its rapid growth due to favourable climatic conditions and a rapid turn over of plant life within the system. The intensity of biochemical activity also results from the rapid rate of decomposition of organic material. This rapidity is due to the conditions in the humid tropics being near the optimum for micro-organisms; very constant temperatures and sufficient moisture to create a culture medium.

If man breaks the cycle, by clearing the natural vegetation and planting his own crops, he is removing the possibility for the soil's fertility to be renewed by the addition of fresh organic matter. When this degradation is accelerated by soil erosion the soil very quickly loses its fertility and becomes unsuitable for agriculture.

In addition to the loss of fertility, due to the removal of humic content, there is also the loss of water retention properties. Since the organic material in the soil plays a large part in helping to retain water, any diminution of that organic matter will cause a decrease in the water retaining power of the soil. Since there is also a decrease in infiltration rate, due to surface compaction and increased surface flow, there is the possibility, especially in the seasonally wet areas, of creating soil moisture deficits in places where this does not occur under natural vegetation. The water that would have been stored in the soil or percolated down to the water table does, of course, go somewhere; it goes into the drainage system which starts to show a marked increase in response time, and increases the probability of causing flash floods lower down the drainage basin. With an increased flow the streams and rivers also develop more erosive power, increasing bank and bed erosion. There is also an increase in the sediment load of the streams which will increase the rate of silting of water storage areas within the system, whether for irrigation or domestic and industrial water supply. This will lead ultimately to increased capital expenditure on either developing new storage areas or in dredging the existing ones. The increased turbidity of the streams may make them unsuitable for industrial or domestic supply because of the increased cost of filtration, and the increased irregularity of flow may necessitate the installation of previously unnecessary water storage facilities.

During periods of flood relatively infertile subsoil, from higher up the catchment, may be deposited on the low lying soils of the basin, damaging crops and imparing the fertility of the soil.

2.5 The problem of soil erosion in Jamaica

The problem of soil erosion in Jamaica is largely a result of the distribution of land use within the island. This distribution is a product of the island's colonial past. All the best agricultural land on the island, i.e. that which was flat, fertile and well watered, was taken by the white settlers for the cultivation of sugar and other tropical crops. The indiginous population having been exterminated during the period of Spanish rule led the plantation owners to import labour, at first from Britain. The first imported labour was not slave, but indentured. Being indentured the plantation owners were determined to obtain the maximum work possible before the indenture was finished, consequently large numbers of the workforce died as a result of over-work, the climate and tropical diseases. The plantation owners found it increasingly difficult to obtain white labour, although there was an increase in supply in the wake of the Monmouth Rebellion and the 'Bloody Assize'. Black labour, in the form of slaves, had been imported by the Spanish to replace the Indians, who had proved to be poor field workers. When the English invaded Jamaica in 1655 the Spanish had freed their slaves who, as the Maroons, were to be a thorn in the side of the British for many years. The idea of importing slaves from Africa was not, therefore, a new one. The system developed of large plantations employing black slave labour, which had to be fed, largely on foodstuffs imported from the American Colonies, and later from the United States and Canada. To this day 'saltfish' (dried, salted cod from Canada) remains one of the traditional Jamaican dishes. Although the slaves were encouraged to supplement their diet, by cultivating garden plots on marginal land owned by the plantation, most small-scale agriculture was carried out by white 'market gardeners' to supply a white market, or by Maroons and runaway slaves up in the hills out of reach of the British Authorities.

When Emancipation came for the slaves in 1834 the freed black workers were not interested in staying on the plantations as wage labour, they wanted to cultivate their own land. Since all the best land was still in the hands of the 'plantocracy' the only lands upon which they could settle were the hilly marginal lands which were unsuitable for plantations.

Plantations also began to encroach upon the hilly marginal lands during the 19th century. These were the coffee plantations which were developed as a result of the boom in coffee prices (it is interesting to note that these lands are being brought back into cultivation as a result of the recent increases in the price of coffee). Plantation agriculture on the coastal plains and in the inland basins had required little or no soil conservation measures, there was thus no history of conservation farming upon which to draw when large scale cultivation of the hilly areas started in the middle of the last century. The results have been devastating, with large areas eroded beyond hope of reclamation.

In the 1920's the first steps were taken to attempt to control the problem. The Afforestation Law 33 of 1927 proved unworkable, and despite many attempts events in the 1930's showed little improvement. The Colonial Development Fund, upon application from the Government of Jamaica, sent a Mr. A. Wimbush (Chief Conservator of Forests, Madras Presidency) to carry out an investigation. Wimbush noted that although the practice of shifting cultivation was currently causing the most damage, historically the most damaging land use had been the wholesale forest clearance to plant coffee. At the height of the coffee boom this would appear to have affected much of the elevated parts of the island, but cannot have been a widespread problem in St. Catherine since most of the land is too low and, except in the north-east, all the elevated areas would have been unsuitable for coffee production due to broken topography and poor, thin soils.

Croucher and Swabey (1937) indicated that the chief causes of soil erosion in Jamaica were unsuitable agricultural practices, poor selection of land for agriculture and a lack of an appreciation of the problem. Both the causes that they observed and the recommendations they made for research and for proper land settlement remain valid now.

Wakefield (1941), an agricultural adviser on the island, pointed out that 'until the present decline in land fertility is arrested in Jamaica, the problems of an excessive birth rate, under-employment and unemployment, inadequacy of medical and educational facilities will remain. Their principle single root cause is undoubtedly soil erosion'.

In 1944 a Soil Conservation Officer was appointed for Jamaica. His duties were stated to be 'to investigate and develop methods of soil erosion control for the different soils and agricultural conditions, to assist and advise in extention work, and generally to promote and encourage the adoption of soil conservation measures'. (Lester-Smith, 1946). Although the Conservation Officer visited most of the Island and made recommendations with respect to soil conservation measures and land use practices, there appears to have been little real response. In the early 1950's the Government adopted a policy of setting up Land Authorities and removed responsibility for agriculture from the Parish Councils who had proved completely inadequate. The first of the new Land Authorities was that for the Yallahs Valley, set up as a result of the Land Authorities Law of 1951. Under this law the Government could declare any area in Jamaica an improvement area and establish Land Authorities for improvement and erosion prevention, and for rehabilitation of the whole area. Authorities were given the power to make by-laws for prohibiting, regulating or restricting the land use and for compensating the loss involved.

Among the early prohibitions in the Yallahs Authority area was bush burning but, as figure 2.1 shows, in March of 1979 the practice was still very much in evidence.

Attempts were also made to control the cultivation of slopes above 24°, either to have them taken out of cultivation altogether, or at least make sure that adequate conservation measures were taken. Figure 2.2 shows a site within the Christiana Land Authority area where slopes well in excess of 24° are being cultivated with no attempt at conservation. Between 1951 and 1961 some £1.1 millions was spent in the Yallahs Authority area with Christiana (established 1954) probably enjoying an even higher rate of annual expenditure.

In 1955 the Farm Development Scheme was inaugurated and spent some £175.000 before 1960 for the conservation and improvement of the island's hill farms.

In the middle 1950's Jamaica was visited by a succession of experts from the Food and Agricultural Organization of the United Nations (FAO). In 1953 Hebel published his report based on work carried out in 1952-53. He noted a large proportion of the conservation work had failed and doubted whether the subsidies being paid were achieving anything. He also noted that much of the mechanical protection such as trenches and barriers, rather than preventing erosion, may have been aggravating it. He recommended setting up a strong, well staffed Soil Conservation Division, a task that has still (1979) not really been accomplished (Conservation Officers are one Civil Service grade lower than Extension Officers in Jamaica, hence the best staff tends to go into extension work where little or

Figure 2.1 Bush Burning within the Yallahs Valley Land Authority Area

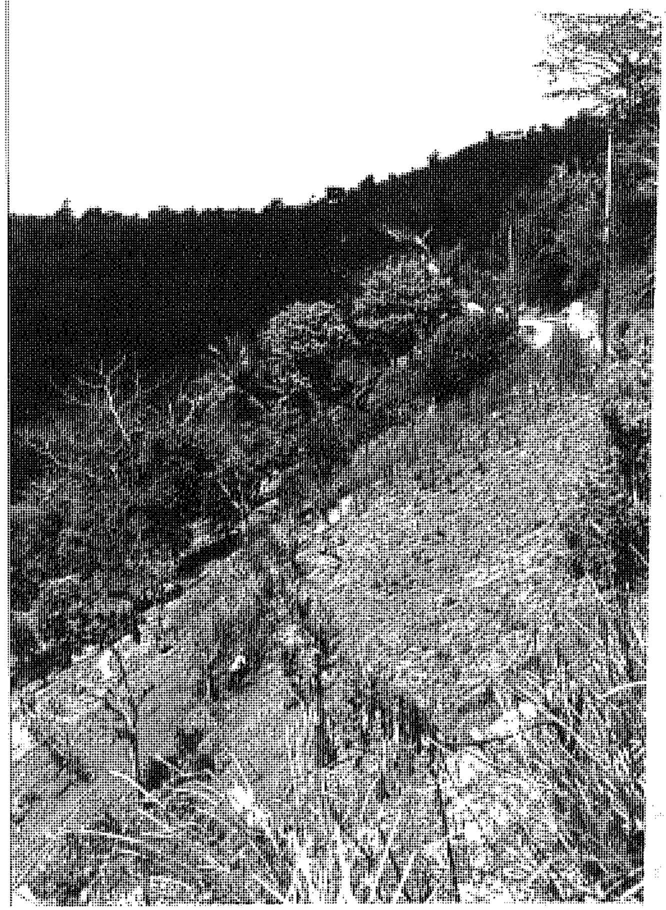


Figure 2.2 Cultivation of Steep Slopes within the Christiana Land Authority Area

no account is taken of conservation).

Dr. Steele, who visited the island in 1954, was responsible for introducing the land capability classification based on that of the United States Soil Conservation Service (see Chapter 3). He also made general recommendations with respect to soil conservation - such as a 20° slope limit on regular cultivation.

Rockie (1956) noted that nearly all the land under cultivation, or formerly under cultivation, had been eroded to some degree. He further noted that the erosion control work currently employed, especially on steep slopes, was not arresting soil erosion but only slowing it down in varying degrees. He stated that 'The erosion control measures must be made more drastic and more intensive if the permanent use of such lands is to be the objective of the work. The present control practices are too frequently only delaying the date of abandonment'.

Dumont, who visited Jamaica in 1962 noted in his report (Dumont, 1963) that over the past decade erosion appeared to have become much worse, and that the measures taken to combat erosion were not in proportion to the extent of the damage.

Reports were also prepared by non-FAO authorities.

In a report on the activities of the Yallahs Valley Land Authority, published by the Division of Economics and Statistics in 1961, it was stated that 'of those soil conservation works that could be assessed, both the standard of execution and the condition of maintenance were, on the vast majority of the acreages, below what might be regarded as effective levels'. It also noted that 'regarless of the standard of execution of these practices, if they are executed on slopes where they should not be established, there is little chance of their lasting for any time'.

Champion (1966) in a study of the upper Yallahs Valley noted that the loss of practically the whole of the topsoil, and the varying degree of subsoil, was the main cause of most of the coffee estates going out of business. He further stated that the rate of soil conservation measures, up to 1966, was too slow to make an appreciable difference to the time that would elapse before further large areas would go out of production through soil erosion, or before yields would fall to such levels that cultivation would no longer be economic and this would lead to further rural unemployment.

More recent work by Sheng (1968) and others have come to the same general conclusions; that not enough is being done in the field of conservation, and that even where work is carried out maintenance is either very poor or non-existent. Certainly there has been no lack of interest in the problem of soil erosion and there have been innumerable attempts to do something about it. Perhaps Hudson (1977) was right when he wrote 'if the known solutions are not being applied, then they must by definition be not the right solutions'. It could also be argued that if they are applied but are not working they must equally not be the right solutions. This is not to argue that conventional wisdom with respect to conservation is necessarily wrong, but rather to make the point that perhaps conventional wisdom takes too little account of the socio-economic and political factors which help to determine whether innovations will be accepted or not. As has been mentioned earlier Okigbo and Lal (1977) made the point that terracing, part of the accepted wisdom and advocated for Jamaica by Sheng and others, is not economically feasible or practical for farms of less than about 5 hectares. In Jamaica

78% of all farms were under 5 acres (approximately 2 hectares) although they account for only 15% of the total acreage (Dept. of Statistics, 1973), and these are overwhelmingly concentrated on the steep marginal lands.

CHAPTER 3

LAND EVALUATION

3.1 Background and Early Systems of Land Evaluation

There have been many attempts at carrying out land evaluation and producing Land Capability Classifications, but those that have been most widely adopted are the ones produced within the United States Department of Agriculture (USDA). The first of these, and the one adapted for use in Jamaica, was devised by Hockensmith and Steele (1943). The second, and latterly more important although not adopted in Jamaica, was devised by Klingebiel and Montgomery (1961). Although rarely adopted in the forms first developed for use within the United States, it has been found that, with only minor modifications, they are suitable for most environments.

There have been a number of different classifications applied in Jamaica but until recently it was the Hockensmith and Steele approach which was most favoured. In recent years, in the aftermath of the United Nations Development Programme (UNDP) 505, an attempt has been made to adapt the 'Treatment-oriented land capability classification scheme (for hilly marginal lands in the humid tropics)' (Sheng, 1972). However, as will be mentioned later, there are certain disadvantages with the application of Sheng's scheme which, although political and socio-economic rather than agricultural, will probably preclude its proper adoption in Jamaica. The Hockensmith and Steele classification, as modified for use in Puerto Rico is, therefore, still very useful for assessing the land use potential of Jamaica, not least because it is still the only one that has been applied to the whole island. It is therefore proposed to deal in some detail with the basic framework used and its development, and also to bring it up to date to deal with the later developments both within the USDA and outside the United States, to cover all the major classifications that have been developed or adapted for use in the humid tropics.

The 1943 classification was not the first one to be developed in the United States but drew on Norton's 'Soil conservation survey handbook' of 1939. Within the United States even earlier attempts had been made to put land use planning on a scientific basis which would allow for maximum land utilisation with minimum risk of soil degradation. Storie in 1933 at the Agricultural Experimental Station of the University of California produced 'An index for rating the agricultural value of soils'. This scheme excludes several of the factors later to be included in the USDA scheme, and uses a 'rating in percent' where the soil index rating = factor A x factor B x factor C. Although more complicated to use than the USDA scheme it does at least have the advantage of compounding the attributes. In the USDA approach this does not necessarily follow. It will be noted later that the Commonwealth Scientific and Industrial Research Organisation (CSIRO) scheme uses the compounding approach, where two or more entries in a class would relegate the soil as a whole to a class lower.

In the USDA Soil Conservation Service scheme 'Classifying land for conservation farming' (Hockensmith and Steele, 1943) eight land capability classes were used. Since they were primarily interested in conservation they used only soil type, drainage, slope and degree of existing soil erosion as criteria for assessing an area's capability. Haggerty and Myers (1940) had listed the characteristics needed (Table 3.1) for a land inventory to develop a land classification.

TABLE 3.1 Characteristics needed for a land inventory (after Haggerty and Myers, 1940)

Soil	**Flood Relationships**
Profile	Frequency
Texture	Intensity
Structure	Duration
Chemical Reation	Occurrence
Content of organic matter and essential plant nutrients	Physical effects
Stoniness	**Land Condition**
Internal drainage	Erosion
	Deposition
Topography	Depletion
Elevation	**Water Resources**
Lay-of-the-land	Kind and extent
Degree of slope	Dependability
	Climate
Native Vegetation	Precipitation
Type	Temperature
Amount or volume	Frost-free period
Quality	Climatic hazards

Haggerty and Myers realised however that it was not sufficient just to describe each land type, what was needed was to group them according to the nature of the adjustments required to fit the land use plan.

This type of approach is, however, of only limited value because it is not directly related to actual or potential use. It was in an attempt to relate characteristics to uses that Kellogg (1935, 1937) came out with his scheme in which "bodies of land are classified (on the basis of physical, or both physical and economic considerations) according to their capabilities for man's use, with sufficient detail of categorical definition and cartographic expression to indicate those differences significant to man".

Kellogg used eight classes for all land use types;

(1) Cropping, (2) Grazing, (3) Forestry, (4) Recreation, (5) Mining, (6) Urban Development, (7) Wild Life Preservation, (8) Protection (Flood control, anti-erosion, etc.)

It is possible to combine classes in this system, e.g. cropping-grazing, grazing-forestry, etc.

With this system the land use classes are determined as much by economic and social factors as by inherent environmental factors. These factors, by their nature transitory and variable, must be considered separately from the permanent, inherent factors. "Any change in utilisation alters the position of the land in the classification of the social land units, whereas the more fundamental classification of the natural land types is essentially permanent. For example, should the boundaries of some proposed grazing or forest district include present cropping land, a reclassification would need to be made giving this land its rating in the new use group in place of its rating in the cropping use group. Where the fundamental physical data are kept clearly separate from the economic or social, as the logic of the method demands, such changes are easily made without additional fieldwork" (Kellogg and Ableiter, 1935).

In the light of this statement it is interesting to note that Jacks (1946) was able to list ten different types of land classification, but it is by no means clear that in these classifications the inherent physical data was being treated separately from the economic and social data.

The ten types listed by Jacks are;

1) Physical classification correlated with economic data
2) Land-capability classification for soil conservation
3) Fractional-code method. Physical and social inventory
4) Economic classification according to attainable intensity of use
5) Classification for extensive wheat production according to profitability
6) Physical classification for land-settlement purposes, without regard to economic and social factors
7) Classification by soil types according to inherent productivity
8) Classification according to present use
9) Classification for land-settlement purposes according to present use, yields and soil-moisture conditions
10) Classification for irrigation purposes

This list could doubtless be added to in the light of the last 30 years work, but it does serve to illustrate the wide variety of types of classification that have been developed for specific purposes, thus ignoring the advice of Kellogg and Ableiter (see above) that the physical data be kept separate from the socio-economic data. We will see later that the advice of Kellogg and Ableiter did not fall on entirely deaf ears and that their approach is closely mirrored by both the USDA and CSIRO systems.

3.2 The U.S. Soil Conservation Service (Hockensmith and Steele, 1943)

The U.S. Soil Conservation Service Land Classification Scheme maps four main characteristics; soil, slope, condition of erosion and present land use. Slopes are measured in percentage and grouped into percentage classes which vary according to the erodibility of the soil type.

TABLE 3.2 Example of USDA Classification (after Jacks, 1946)

Soil Type 1		Soil Type 2	
Slope Class	% Slope	Slope Class	% Slope
A	0-3	A	does not occur
B	3-8	B	" " "
C	8-15	C	15-25
D	15-25	D	25-35
E	does not occur	E	35 and over

Erosion conditions are expressed by numerical symbols indicating the degree and kind of erosion. They are standard to the Soil Conservation Service, e.g. 3 indicates 25-50% and 33 indicates 50-70% loss of top soil, 7 indicates occasional gullies more than 100 feet apart.

Land types were also given a three part symbol in which the first part refers to erosion conditions, the second to the slope and the third to the soil type, e.g. 337-B-16.

A new land type is mapped whenever one part of the symbol changes.

Present land use is mapped separately and is indicated by capital letters - L, cropland; H, farmsteads; P, pasture; F, woodland; X, idle land. Present land use is mapped to show where land is being poorly used and where adjustment are necessary.

On the basis of the three characteristics the individual land unit is classified according to its capability or suitability for agricultural use. Eight classes are used.

Suitable for cultivation with:

I No special practices

II Simple practices

III Intensive practices

Suitable for occasional or limited cultivation with:

IV Limited use and intensive practices

Not suitable for cultivation, but suitable for permanent vegetation with:

V No special restrictions or practices

VI Moderate restrictions in use

VII Severe restrictions in use

Not suitable for cultivation, grazing or forestry:

VIII Usually extremely rough, sandy, wet or arid land that may have value for wildlife

On the basis of the above a table is drawn up of recommended agricultural practices for each class of land - alternatives would normally be available. Recommendations would also be made with respect to conservation practices.

This classification system is largely one of soil rather than land and it has only one real purpose - the control of soil erosion. For areas with a large soil erosion problem such a scheme, using a limited number of variables, is often preferable to an expensive complete land inventory system.

As Jacks observed the purpose of a soil-conservation survey might be described as planning for permanent settlement, since without adequate soil conservation permanent settlement and long term land planning are impossible. He agrees with Eisenhower (1941) that Western Europe (although it might be preferable to speak of North-West Europe) is the only developed region of the world practising 'total soil conservation' and that 'the pre war pattern of land use was the resultant of farming systems evolved primarily for soil conservation and modified within the soil-conservation framework by economic, political and social factors'. Whether it would be possible to agree with this statement today, in the light of the modern farming technologies employed in Western Europe, is a matter of debate. Jacks believed, however, that those countries evolving towards a more settled state should also base their land-use planning on soil conservation and at that time regarded the USDA as being the fundamentally most sound and therefore the one to be applied.

3.3 The Tennessee Valley Authority

The Tennessee Valley Authority (TVA) scheme took into account the 'human' factors to a far greater extent than any comparable land capability classification. This was, to a large degree, because of the peculiar economic and social problems of the area, the result of over 150 years of bad agricultural practices.

This scheme takes into account major land use, agricultural emphasis, field size, amount of idle land and quality of farmsteads and equipment. The physical conditions used for classification are slope, drainage, erosion, stoniness, rock exposure, soil depth and soil fertility.

This scheme was very well suited to the particular conditions of the Tennessee Valley since much field work had already been done. A similar scheme has been used in New Zealand.

3.4 United States Department of Agriculture Land Capability Classification

The USDA scheme (Klingebiel and Montgomery, 1961) was the first attempt made to apply a parametric approach to land use capability mapping. This is now probably the most widely used classification and has had a great influence on the systems which followed (e.g. Bibby and Mackney, 1969 and the Canadian Land Inventory, 1965). The system seeks to assess the 'land capability from known relationships between growth and management of crops and physical factors of soil, site and climate' (Bibby and Mackney, 1969). Eight capability classes are used, one to four being those suitable for cultivation and other uses, five to eight are those unsuitable for cultivation and having only limited suitability for other purposes. The capability sub-classes are defined on the basis of the physical factor or factors limiting production and are indicated by a subscript letter added to the class number. These are the lowest categories used in the classification and group the soils capable of growing the same crops and requiring the same management. Long-term estimates of crop yields for individual soils should be within 25% of the true values.

The sub-classes used are 1) erosion, 2) excess water, 3) soil limitations (e.g. depth, stoniness, low fertility etc.) and 4) climatic.

Table 3.3 gives a summary of the potential uses and limitations of the eight classes of the USDA system.

3.5 Schemes derived from the USDA Classification

In the classification adopted by the Soil Survey of Britain the USDA class 5, which allows mainly for wet soils in level sites poorly adapted for arable crops, was deleted, reducing the number of classes to seven. A further sub-class, indicated by the subscript g, was added to allow for gradient and soil pattern limitations on land use.

Additionally the Agricultural Land Classification of England and Wales published by the Ministry of Agriculture,

Table 3.3 Summary of criteria for USDA land classes (after Klingebiel and Montgomery, 1961)

TYPE OF LAND USE	I	II	III	IV	V	VI	VII	VIII
	(suited to cultivation and other uses)				(generally not suited to cultivation)			
1. Crops	+	+	+	+				
2. Pasture	+	+	+	+	+	+		
3. Range	+	+	+	+	+	+	+	
4. Woodland	+	+	+	+	+	+	+	
5. Wild life	+	+	+	+	+	+	+	+
LAND ATTRIBUTES								
6. Slopes	Level	Gentle	Moderately steep	Steep	Gentle	Steep	Very steep	Very steep
7. Erosion hazard	None	Moderate	High	Severe	Severe	Severe	Severe	Severe
8. Overflow danger	None	Occasional	Frequent	Frequent	Frequent	-	-	-
9. Soil depth	Ideal	Less than ideal	Shallow	Shallow	Shallow	Shallow	Shallow	Shallow
10. Soil structure and workability	Good	Somewhat unfavourable	-	-	-	-	-	-
11. Drainage	Good	Correctable by drainage	Very slow	Water-logging	-	Water-logging	Water-logging	Water-logging
12. Water holding capacity	Good	Moderate	Low	Low	Low	Low	Low	Low
13. Salinity	None	Slight to moderate	Moderate	Severe	-	Severe	Severe	Severe
14. Nutrient status	Good	Moderate	Low	-	-	-	-	-
15. Climate	Favourable	Slight	Moderate	Moderately adverse	Unfavourable	Unfavourable	Unfavourable	Severe
16. Management practices required	Ordinary	Careful	Special	Occasional cultivation only possible	Cultivation not possible			
17. Stoniness	-	-	-	-	Some	Severe	Severe	Severe

Fisheries and Food (1968) employs a simpler five class scheme. Class I has very minor or no limitations and class V has very severe soil, relief or climatic limitations and should only be used for grass or rough grazing. This classification has been used to compile the maps of England and Wales at 1:63,360.

3.6 The Commonwealth Scientific and Industrial Research Organisation (CSIRO)

The CSIRO has always tended to tailor the land capability classification scheme to the individual case under study. This reflects the wide range of terrain types, climates and environments with which the CSIRO has been involved. The criteria used in Papua New Guinea or Northern Queensland would hardly be suitable for the arid regions of the 'Dead Heart' of Australia.

The CSIRO also pioneered the Land Systems approach to land classification as a means of carrying out rapid surveys of large areas as quickly as possible. Since their pioneering work in the late 1940's a number of other organisations, such as the Land Resources Development Centre (LRDC), the Transport and Road Research Laboratory (TRRL), and the National Institute of Road Research (NIRR, South Africa) have become involved in this approach. These organisations later got together to co-operate in the Oxford-MEXE group. The Oxford-MEXE group was set up to produce a single land systems approach which would be usable by all those currently using similar systems or any others who might feel, in the future, the need for such a system. The work carried out by the Oxford-MEXE group is sufficiently well documented, Beckett and Webster (1969), Ollier, Lawrance, Webster and Beckett (1969), Murdock, Webster

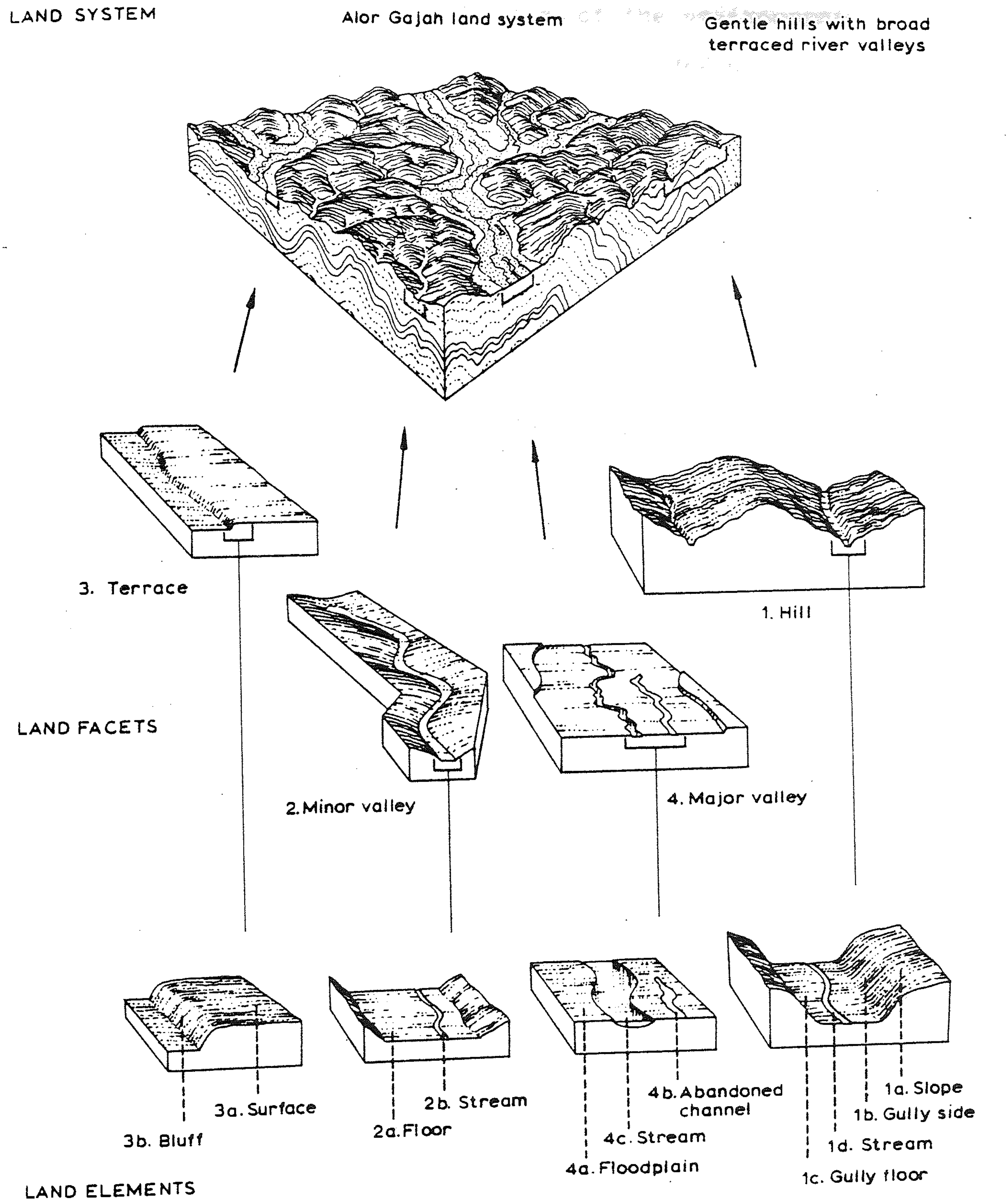


Figure 3.1 Schematic Diagram of the Land Systems Hierarchy (after Lawrance, 1972)

and Lawrance (1971) etc., that there is little point in carrying out a detailed examination of it. This particular system derives from a 'holistic' view of the environment. There are seven categories of terrain, each defined by a combination of climate, geology, and landform. These are, in decreasing order of size;

Land Zone

Land Division

Land Province

Land Region

Land System

Land Facet

Land Element

3.7 Tropical Systems

Land capability studies in the tropics have always been the poor relation of those carried out in Europe and North America. Colonial neglect and lack of funds have largely been responsible for this situation.

The survey published in 1938 by the Imperial Bureau of Soil Science on Erosion and Soil Conservation (Jacks and Whyte) highlighted the magnitude of the problem of soil erosion in the tropics, and the almost total lack of knowledge related to land capability and effective land use planning. Jacks (1946) outlined some of the then available land use capability classification systems, none of which had been developed for use in the tropics. The first organisation to approach the problem of tropical land use capability in anything like a systematic way was the CSIRO. At about the same time, however, Alicante and Mamisao (1948) were drawing up a classification scheme for use in the Philippines, but this was far from systematic and relied heavily on subjective decisions on capability. Hernandez (1955) applied the score-card approach to the classification of Alicante and Mamisao in an attempt to make the ratings more objective. The approach was in some ways very similar to that of Storie and so need not be dealt with in any detail. The factors used in classifying potential were soil (profile, surface texture, fertility, drainage, reaction, overflow hazard, presence or absence of alkali), slope and erosion. Soil characteristics account for 50% of the rating; slope and erosion for 25% each. These are summed and the resultant figure is the rating. The system is obviously defective in that one very adverse factor will not reduce the final rating figure sufficiently to take it from a productive class into an unproductive class. For example a good soil on a steep (45%) slope with no present erosion problems (due to it being under natural vegetal cover) could score up to 77%, which puts it in a cropland class. A multiplying system rather than a summing system of scoring would obviously have been a better approach.

Lewis (1952) writing in an F.A.O. development paper on the classification of land for agricultural development, lists only one classification system for tropical land use, and that was one he was preparing for the Department of Agriculture in Puerto Rico. Stephens (1953) in a further F.A.O. study, fails to mention even one tropical land capability classification. Swabey (1957) on the 'Selection and dedication of land for forestry in Uganda' is one of the earliest classifications (and even this one is product specific) that it has been possible to identify. Edelman (1948) and de Haan (1950) carried out earlier work in Indonesia but it has not been possible to obtain copies of the classifications used.

3.8 Sheng's Scheme adapted for Jamaica

Sheng's Treatment-oriented land capability classification scheme (for hilly marginal lands in the humid tropics) derives from the USDA classification, but has been modified to take account of the differences in agricultural practices, crops and socio-economic conditions in the tropics. Originally developed in Taiwan the scheme has been recently applied in Puerto Rico and Jamaica. The basic principles and assumptions of this scheme are summarised below.

1) The classification is primarily for agricultural purposes, but it is not a soil suitability classification for specific crops.

2) The capability classification is based on the permanent limiting factors - physical rather than chemical - of soils, slope, erosion and climate. Factors that can be easily removed are not considered as permanent limitations. The varying initial costs of removing such limitations do not affect the classification.

3) The capability classification is not a productivity rating; nor are the soils grouped according to the most profitable use of the land.

4) Land is assessed on its capability under a moderately high level of management and not on its present use.

5) Land is classified according to the most intensive tillage that can be practised safely with permanent maintenance of soil. A lower use is permissible, for example land suited to cultivation is also suited to pasture, range and forest. Use beyond the capability limit should be discouraged or prohibited. (For the limitations of this with respect to Jamaica see Chapter 2).

6) Capability classes are homogeneous only with respect to degree of hazards or limitations in agricultural use. Each class may include many different kinds of soil.

7) An economic classification of lands should be kept separate from a land capability classification.

8) Land should be reclassified when (I) major reclamation projects are installed and (II) farming methods not previously known are introduced. Lands which can feasibly be improved are classified according to their continuing limitations in use after the improvements have been installed.

There are in addition assumptions related specifically to tropical land use.

1) Due to problems of food shortage, unemployment and under-employment in the tropics, any land which can be cultivated by hand should be classified as suitable for cultivation.

2) Any land which by bench terracing, or some other conservation method, can be protected from erosion should be classed as land suitable for cultivation.

3) Soil conservation is a must and a pre-requisite for marginal sloping lands to be brought into cultivation. The land should be classified according to the expected results of such treatment.

4) The scheme should be simple enough for semi-skilled staff to apply.

Sheng appears to draw upon the work carried out by other Taiwanese soil scientists in the late 1940's and early 1950's. Notable among them are Hsia (1953) and Hsi (1953). Hsia examined the particular needs of a country where much of the land is not suitable for agriculture in the western sense, but where population pressures mean that all land of even low capability must be pressed into service. He points out that the USDA system (Hockensmith and Steele 1943) was quite unsuitable for classifying land capability in Taiwan, and that a new system needed to be developed. Hsi goes some way towards proposing a new classification scheme but it still falls short of the full treatment-oriented approach of Sheng. Unfortunately it has not been possible to obtain English translations of the papers that may bridge the gap between the early 1950's and Sheng's work in the late 1960's.

CHAPTER 4

LAND USE AND LAND USE CLASSIFICATION

4.1 Introduction

An assessment of the different types of land uses and their spatial distribution in Jamaica is impossible without an understanding of the historical development of agriculture on the Island. The chief reason for this is that the inequitable distribution of land between large estates and small peasant farmers is still largely a legacy of the colonial past.

The rich, flat alluvial lands are still dominated by the plantations, still largely white owned and still engaged upon monoculture for export. Until the nineteenth century these plantations were engaged almost exclusively upon the production of sugar. Although Jamaica also produced indigo, pimento, logwood and other tropical products, they were not extensively cultivated nor confined to the flat lands. During the course of the nineteenth century the monopoly of sugar was broken, largely in the wake of emancipation when labour costs soared and the price fell, and there was increased diversification into citrus, coconuts, beef and, later, bananas. At the same time coffee plantations were being developed in the upland areas of the island, especially the Blue Mountains. Cattle ranching had been established since early Spanish times on the drier areas of Southern Jamaica and in the bauxite lands of St. Ann, when Jamaica had been used as a provisioning ground for the exploration and conquest of Mexico and Central America. In the wake of the 'sugar depression' the raising of cattle was extended into areas such as Lluidas Vale and St. Thomas in the Vale, hitherto given over almost exclusively to producing sugar.

With all the best land given over to the production of tropical staples the local market came to be supplied by small-holdings established in the hilly marginal lands or by imported foodstuffs. Such was the importance of imported food that two of Jamaica's national dishes, 'ackee and salt-fish' and 'peas and rice' rely on imported produce despite it being said that almost anything will grow in Jamaica. Additionally the small-holdings produced staples such as sugar and bananas; the cane being sold for processing in the estate factories. In 1772 there were 775 factory-estates in Jamaica, that is areas of land serving a separate factory (there were perhaps as many as 1061 holdings producing cane). The number of factories declined quite rapidly from this peak figure until there are only 15 today. Fortunately one of the oldest and best documented lies within the study area and it would be useful to look, briefly, at its history.

Worthy Park was founded in 1670, just fifteen years after the English conquest, in an area which, being completely surrounded by limestone hills, had not been developed in Spanish times. Since being founded by Francis Price on 840 acres of the Lluidas Vale the plantation has been in almost continuous sugar production. The date of the establishment of the first factory is not known and it is probable that initially sugar was processed at a factory on a neighbouring estate. Almost certainly it had its own factory by the 1690's which became water powered around 1752. Despite the decline, starting about 1790, that affected the Jamaican sugar industry, the plantation prospered reaching a peak of production in 1812. Thereafter the estate, following the general decline of the industry, accentuated by the loss of the protected sugar duties and Emancipation, was sold as an Encumbered Estate in 1863 after nearly two hundred years in the same family. Even during the worst of the slump in sugar prices the estate continued to produce sugar and, under a succession of owners, the acreage was increased towards its present 12,000 acreas as the surrounding estates went bankrupt. Helped by the boom in prices following the First World War the estate prospered and has been able to survive the periodic slumps in prices. In terms of overall efficiency the estate became the best on the island in 1968. This is in part a result of the management, but it is also due to the unique geographical situation said to be near the ideal for sugar production, and the long periods, up to 18 years, between replantings.

In common with the other estates Worthy Park has diversified into cattle and citrus to provide a broader economic base and protection against the fluctuations of the sugar market.

Apart from the Maroons and runaway slaves there is little evidence of the cultivation of the upland areas much before Emancipation. Presumably the vegetable patches of the slaves were located on the marginal land around the estate, but would not have extended far into the hills. Pimento, which occurs naturally on the island, timber and any other forest products were certainly exploited in the period before Emancipation but this was largely unsystematic and, except near the coast or major rivers, can have had little effect on the environment. The 'watershed' in the development of the hilly marginal areas came with Emancipation in 1834, four years after the abolition of slavery. The liberated slaves were not content to remain on the plantations where they had once been slaves and since there were large parts of the island, almost exclusively the upland parts, that had not been settled, there seemed no reason to remain as plantation workers. This is in contrast to other Caribbean Islands, such as Barbados, where most of the land was already in cultivation, thus forcing the liberated slaves to remain as wage labour since they could not farm small-holdings of their own.

There were, therefore, two effects of Emancipation on Jamaica, the first was the development of the upland areas by peasant farmers, often with no knowledge or experience of farming other than on plantations or vegetable patches, where the risk of soil degradation was slight due to the flatness of the land and its high fertility. The second effect was to produce a labour shortage on the plantations. To combat this the owners tried to import indentured labour, first from India from 1842 and later from China from 1854. The conditions and treatment were such however, that after a few years the Government of India stepped in and stopped further recruitment. The economic decline of the plantation that had started about the time of the Napoleonic Wars continued, aggravated by the labour shortage.

Other plantation crops show similar patterns of growth and decline, and all have had their effect on the land use pattern although none, with the possible exception of bananas, has had as profound an effect as sugar.

The exact date of the introduction of bananas is not known although it has been established that they were introduced from the Canary Islands. For much of the history of cultivation on the island production would have been sufficient to satisfy only the local market. The variety upon which the banana industry was to be based, the Gros Michel, was introduced into the island from Martinique in 1835 by Jean Francois Pouyat, a French botanist. It is the same variety upon which the industries of Fiji, Colombia, Central America, Surinam and Australia were to develop. The variety is, however, susceptible to Panama Disease which has led to its being replaced by more resistant, if less desirable, varieties such as Lacatan. The export industry was largely developed in the late nineteenth century by the United Fruit Company and at its peak was a bigger earner of foreign exchange than even sugar. Peak production was reached in 1937 when 27 million stems were exported, but the Second World War caused a decline from which the industry has never really recovered. In the 1950's ten to eleven million stems were exported annually, production rising through the 1960's to peak again at nineteen million stems in 1971. By 1974 8.5 million stems were exported, rising again to 11.5 million in 1977. The industry has thus seen rapid changes in the pattern of land use. Fortunately by its nature, banana cultivation causes no real problems of soil degradation, except through a build up of nematodes, thus the rapid expansion and contraction of the growing area pose no great threat to the land unless excessively steep land is cultivated. The same cannot, however, be said of another crop that has seen rapid increases and decreases in production - and that is coffee. The expansion of the coffee plantations towards the end of the last century was responsible for wholesale clearance of forest land, especially in the Blue Mountains. Much of this land is very steep, often in excess of 40°, which, when cleared, eroded very rapidy. Considerable areas of these badly eroded lands are now being planted with the Caribbean Pine. Some less eroded lands are being brought back into cultivation in the wake of the boom in coffee prices caused by the Brazilian frosts. Other areas are still practically useless for commercial use, being either poor mineral soils without organic content or almost pure shale.

There have been wild fluctuations in the production of other plantation crops, but of more recent years these have been more a function of the low rainfall in the middle 1970's than of market fluctuations, and are not, therefore, reflections of a decline in acreage planted.

4.2 Land Use Classification

When this research programme was being initiated one of the factors which led to Jamaica being chosen as the test area was the existence of a complete agricultural census carried out in 1968, the same year as the entire island was flown for photographic cover. It was felt that this census would give an independent check on the accuracy of the land use mapping and hence save considerable time and effort at the field checking stage. Although the classification used by the Census of Agriculture (1973, 1974) was used in devising the classification scheme for this programme, it was found, upon application, to be inappropriate to the work being carried out. As a result of experience gained during the photo-interpretation stage the classification was modified and two classes removed entirely. A more detailed treatment of the changes necessitated and the reasons involved is given in section 4.3. This section will deal with the various land use classification schemes devised, with special emphasis upon those designed for use in conjunction with aerial photographs, and the reasons for them being considered unsuitable for the present purpose.

The Jamaican Agricultural Censsus Unit carried out its work as part of the World Agricultural Cenus Programme. In the light of this it might have been expected that the classification scheme used would bear some resemblance to that devised by the Internation Geographical Union (IGU). In fact the classification bore little resemblance to that of the IGU: most of the definitions used were the same as those of the 1961/62 and earlier surveys. It seems that the census organisation was more concerned with maintaining continuity between the different Jamaican surveys than in trying to fit into an international scheme.

The definitions of the Jamaican Agricultural Census Unit are listed below:

<u>Crops in Pure Stand</u>

Any crop which alone occupies at least one square of land (one square being defined as 1/10 of an acre). In cases where tree crops were inter-cropped with particular types of herbaceous crops, root-crops, pulses or other such crops the major crop as determined by a specific formula was included as pure stand.

<u>Crops in Mixed Stand</u>

All herbaceous crops (tubers, pulses etc.) or tree crops interplanted or mixed; for example coconut and limes interplanted with cane.

<u>Food Forest</u>

This was the definition given to cases where a canopy of tall economic trees existed (breadfruit, star-apples, mango, avocado, pears, etc.) in association, with or without a lower canopy of cocoa, coffee, citrus and other smaller trees and shrubs and sometimes a third layer of herbaceous crops, in spaces where the light permits such as kale or calaloo. Scattered tree crops were not included in the area of food forest.

Improved Grassland

Cultivated grassland i.e. grassland on which labour had been employed or any money had been spent.

Natural Grassland

All grassland in which grass grew without irrigation, fertilization or the utilization of any form of labour for maintenance.

Fallow

All the cultivatable land which had not been used during the year proceeding Cenus Day but which had been cultivated in the past or which it was planned to cultivate in the near future. In fact what was classified here was land that was being rested. Land in berries and small fruits of non-bearing age was included but not land in mature fruit trees, nut trees or vines of non-bearing age.

Ruinate used as Pasture

Land which once had been in cultivation but which on Cenus Day was then covered in weeds and scrub with probably a few low trees but not dense woodland. Extremely rocky land or steep land of no agricultural value was not included.

Woodland

All acreage covered by forest growth. The trees in this woodland category were of economic value as fire wood or lumber for the manufacture of wood products. The great difference between the Jamaican Census classification and that of the IGU is that the Jamaican Census was entirely concerned with what each particular piece of land was being used for on the day of the census, December 1st 1968, while the IGU is concerned with the 'normal' usage of the land.

The IGU land use classification is listed in table 4.1.

TABLE 4.1 International Geographical Union (IGU) Land Use Classification

1) Settlement and associated non-agricultural land
2) Horticulture
3) Tree and other perennial crops
4) Cropland a. continual and rotation cropping
   b. land rotation
5) Improved permanent pasture
6) Grassland and scrub, used and unused
7) Woodland a. dense, b. open, c. scrub, d. swamp, e. cutover or burnt over forest areas, f. forest with subsidiary cultivation
8) Swamp and marsh
9) Unused land

It was felt that, for the purposes of the research programme, the more general approach to land use of the IGU classification was more suitable than the Jamaican Census Unit classification. As is mentioned below it was felt that as the programme was concerned to discover if a relationship existed between land use and soil erosion it could well be misleading if only one year's use was taken into account.

If the 4b. classification of the IGU is taken as an example it is possible to highlight the shortcomings of the

Cenus classification. In the humid tropics the system of land rotation normally entails land being cultivated for about three years and then rested for six or seven years. In areas of rich soil the ratio of cultivation to fallow would be greater, and on poorer soils it would be lower. If we take the average, however, one third of the land will be in cultivation at any one time and two thirds will be in fallow. In the IGU classification all this land would be classified as 4.b. but in the Jamaican Census classification the land could be classified as any of four different classes; Crops in pure stand, Crops in mixed stand, Fallow or Ruinate. Given that there will be twice as much land being rested as cultivated, it would follow that in an area of homogeneous soils and slopes it should be possible to identify more than twice as much soil erosion features on the fallow and ruinate land as on the cultivated land. The problem is, however, that the soil erosion is not caused by the land being rested, but by it being cultivated, thus any correlation between rested land and soil erosion would be meaningless in terms of trying to determine what type of land use is most harmful. Instead of indicating that land is rested because of soil degradation, the statistics would show that the soil is degraded because it is being rested. It is important, therefore, to make sure that the land is always classified according to the most intensive land use, since this will usually be the one that causes most soil degradation. It follows, therefore, that the IGU approach to classification is closer to the needs of this programme than that of the Jamaican Cenus. Unfortunately although it will be found that the classification used for this research programme has much in common with the IGU classification, it was found that the IGU classification failed to make certain distinctions which were felt to be important.

The IGU classification was considered to be most deficient in failing to differentiate between the different scales of continuous or rotational cropping. During the preparation of the programme it became evident that there were marked differences between the methods of cultivation used on the small-scale, peasant farms, and those used on the large-scale, commercial farms; even where both were practising continuous cropping. Cultivation techniques are also dependent upon the type of crop being grown, but although this is not taken into account by the IGU classification it would be possible to add a further letter or number to the classification to take account of the major crop types. If, however, this had to be added to a cropland classification that already had been sub-classified according to cropping system and farm/field size, there would already be a four character classification before allowing for the presence of mixed classes and other complications such as multi-cropping.

To avoid the problems of classification, inherent where multi-cropping systems are involved, Sridas (1966) mapped only the dominant crop. This approach was felt to be unsatisfactory for two reasons. The first is that the interpreter is still left with the problem of deciding which is the dominant crop in an area where two or more crops may be grown together. Which criteria are to be used? Economic value, number of plants, area of ground cover and identifiability could all be used to determine the 'dominant' crop, but none is really satisfactory and, more important, capable of being readily applied in an objective way. The second objection is that, even if it were possible to determine objectively which is the 'dominant' land use, to map the dominant usage only is falsifying the true nature of the land use, and could well lead to misleading results when the attempt is made to correlate land use and soil erosion. Certainly this would be the case if the dominant crop were a perennial tree crop, such as coconuts, with a second crop of a vegetable which is cultivated with clean tillage, such as sweet potato or dasheen both of which, on slopes, are considered to be an erosion risk. Despite the cover from the coconuts providing some protection from rain impact, the expected rate of erosion would still be much higher than for coconuts in pure stand. The exposed roots of the coconuts, when grown in conjunction with ground crops, would certainly support the view that there had been a general lowering of the land surface due to soil erosion. Exposed root systems are not characteristic of coconuts grown in pure stand.

Collins (1972) in his classification of land use in St. Catherine based on the 1961 aerial photography, classified land use according to crop or natural vegetation. His study included the whole of St. Catherine and thus included land use and vegetation types not found in the northern part of the parish (salinas, mangrove swamp, etc.). The main shortcoming of this classification system, with respect to the present reserach programme, is that it took no account of farm size which, as was mentioned above, is an important factor in determining the cultivation techniques and practices.

Panton (1970) in his land use classification scheme for use in Malaysia, resembles that of Collins (1972) but includes categories such as shifting cultivation and annual and diversified crops. Unfortunately again no attempt is made to take account of farm/field size, rendering the classification unsuitable for application in this research project. The classification of Panton (1970) so resembles that of Collins (1972) that it would seem that the variation between them is more a function of the different landscapes for which they were intended, than to any differences in the purpose of the classification.

The land use or cover classification of the United States Geological Survey (USGS) as given in Witmer (1977) was specifically designed for use with remote sensing imagery. Unfortunately this classification, probably because it was originally designed for use in the continental United States, also fails to take account of the different types of agricultural practices which are related to size. The USGS classification also suffers from the defect that, in being a total land cover system at its first level, it is too general for other than small-scale mapping. By the time it reaches an acceptable level for the scale of mapping envisaged for this project, it already involves the use of three character codes before allowing for mixed classes. It was felt that for ease of application no more than four characters should be used to classify a land use - even when dealing with a mixed land usage. It was felt that interpretation would be made too unwieldy and much slower if a more complicated code was used. It was also felt that the analysis would be made too complicated if there were too many land use variables. The classification employed had to be sufficiently simple to be readily usable, but sufficiently close to reality to make the results of the analysis worthwhile.

Although the Jamaican Census classification was not of great value in producing a classification scheme for this work, the statistics produced by the census were extremely helpful in deciding which criteria to use.

Appendix B gives the more important of the statistics but it will, perhaps, be useful to summerise some of the statistics which helped determine the form of the classification.

As is mentioned below, it became evident during the preparation of this project that there were marked differences between the land use on the large farms and that on the small, peasant farms. Although this was indicated by observation of the photographs during a preliminary study of the area, it was highlighted by an examination of the statistics. In farms of more than 100 acres 97.7% of cropland is in pure stand, while in the less than five acre class only 45.2% of cropland is in pure stand. In the less than five acre class 70% of land is cropped while only 29.5% of the 100 acre plus class is cropped. Fallow formed 4.9% of total land use in the less than five acre class, but only 0.8% of the 100 acre plus class. The food forest, grassland and woodland statistics also show marked differences between the different farm size classes. It is less easy to quantify the quality of cultivation within the different size classes, but these differences are real and important in terms of their impact on the relative rates of soil degradation. Information is provided on the use of fertilizers, adoption of new crops and abandonment of existing ones, but there is little information on the adoption of innovations in agricultural practices and conservation practices. It was with the importance of differentiating between large-scale commercial and small-scale subsistance cropping in mind that the classification in table 4.2 was drawn up.

When the classification came to be applied it was found that class 9 (swamp and marshland) did not occur within the study area, although such a class would be necessary for a study of the whole parish. Classes 4 (fallow) and 5 (ruinate) were also not used for reasons given in section 4.3.

TABLE 4.2 Land Use Classification Developed for use in this Research Programme

1. Plantation
   - a. Sugar)
   - b. Citrus) Pure Stand
   - c. Banana)
   - d. Palm)
   - e. Other
   - f. Mixed Stand (or use combination of two from above)
2. Cultivation - Subsistence, Horticulture and Market Gardens
   - a. Sugar)
   - b. Citrus) Pure Stand
   - c. Banana)
   - d. Palm)
   - e. Other
   - f. Mixed
3. Grassland and Pasture (including scrub pasture land)
   - a. Improved
   - b. Unimproved
4. Fallow
5. Ruinate
   - a. Used as Pasture
   - b. Other
6. Woodland
7. Food Forest
8. Urban, Industrial and other non-agricultural land use
9. Swamp and Marshland

4.3 Land Use Characteristics

Without a good understanding of the fundamental characteristics of the different land use types it is not possible to proceed to a coherent classification system, nor to positively identify the different types on the aerial photography.

The most important land use types from the soil conservation point of view are those practised on the hilly areas of the island. These are also the land use types which pose the greatest problems in both categorisation and identification. Sheng (1973) indicated that land with slopes in excess of 20° accounts for over 50% of all land on the island. He furthermore regarded these lands as constituting 'the most serious problem in Jamaica's watersheds'.

In the upland areas, which are mainly composed of limestone, there is an extremely intermittent pattern of land use. Small areas planted in a variety of field crops, and often multicropped, alternate with scrubby grassland and various types of woodland. This extremely irregular pattern of land use poses great problems for classification, both on the ground and on aerial photographs. Viewing aerial photography of various dates soon shows how transitory the pattern is: an area which appears as woodland on one set of photography will appear as mixed cultivation on a set taken a few years later, and on a still later set will appear as rough pasture - or even dense scrubland already reverting to woodland. It is not possible to get an accurate idea of how much of the land is in cultivation at any one time. In some areas it may be as high as 50% while in others as low as 5-10%. This would seem to be a function of both the rate at which the soil regains its fertility and of the pattern of land tenure.

Thus the areas of Granodiorite, Andesite, Shale and Metamorphosed rocks often show a higher density of active cultivation than the areas of limestone. There are also marked differences within the limestone; but this appears to be more a function of morphology than of limestone type. Additionally those areas of very small holdings show a greater density of cultivation than do areas of extensive holdings. The problems are, therefore, how to define the types of cultivation being practised, their relationship with the surrounding woodland and how to map this scattered pattern. Ahmad (1977) clearly considers this to be an example of 'shifting cultivation' but large areas would certainly be excluded under Ruthenberg's (1976) definition. Here if more than 33% of the arable or temporarily used land is cultivated annually it should no longer be defined as 'shifting cultivation' but ought to be considered a 'fallow' system.

Manshard (1974) defines shifting cultivation as a 'type of economy in which both economic area and settlement are moved at certain intervals (Wanderfeldbau)'. While wishing to keep the distinction between shifting cultivation and land rotation (short or long fallow) he does not state how a determination is to be made in the case of a particular example except, perhaps, for his reference to shifting settlements. He regards as a minor exception shifting cultivation as practised by permanently settled people. Very few other authorities put such stress upon whether the cultivators do or do not change their place of residence during the cycle of moving the area of cultivation.

Greenland (1974) used a more general definition writing that shifting cultivation was 'very broadly any system under which food is produced for less than 10 years from one area of land, after which that area is abandoned temporarily and another piece of land cultivated. The houses of the cultivators may or may not be abandoned when the land is abandoned; usually they are not. The abandoned land will be recultivated after its fertility is judged to be restored, or sooner if other land is not available for use'. There is a basic disagreement here with Manshard although Ruthenberg is reconcilable to both.

Ofori (1974) supports Manshard when he states that shifting cultivation and land rotation are the same in terms of agricultural practice, but that shifting cultivation entails a change in the place of residence. Mouttapa (1974) treats shifting cultivation and bush fallow rotation as synonymous. Allan (1965) states that 'land rotation cultivation' should be employed as the general term, restricting the use of shifting cultivation to the extreme variants where 'the whole community of cultivators moves'. Moody (1974) defines shifting cultivation as a system in which periods of fallow exceed periods of cultivation, but does not say by how much.

Thus the system of cultivation in the upland parts of Jamaica may or may not be shifting cultivation. There are, however, at least two other possible terms applicable to the system of cultivation. The most important of these are fallow systems and ley systems. Allen's (1965) 'land rotation cultivation' has been excluded because it is too imprecise, being equally applicable to what most others would consider shifting cultivation, fallow or ley systems.

Ruthenberg (1976) defined a fallow system as one where 50% of the land is cultivated annually. The fallow vegetation would normally be grazed by cattle, sheep or goats and the period of fallow should be insufficient for the forest vegetation to regenerate. If the fallow vegetation is systematically grazed then Ruthenberg would term it an unregulated ley system. A fallow system is according to Ruthenberg (1976) 'usually characterised by clearly defined holdings with permanent field divisions. Quasi-stationary housing predominates, since the changing of hut sites is a matter of moving short distances only. Families generally have de facto or registered ownership of land, in contrast with most shifting systems, in which the holding boundaries are not usually clearly defined, housing is more or less of a migratory nature, and land rights are even less precisely defined'. A ley system is basically one where cultivation of the land is alternated with grazing whether in a systematic or an unsystematic way. There may or may not be an attempt to improve the pasture depending on the intensity of grazing and the financial resources of the owners.

Unfortunately the picture presented by the upland areas of Jamaica does not readily correspond with any of the systems defined above. Within the island there is de facto or registered title to all the cultivated land. The house or hut of the cultivator remains in the same place throughout the cycle of land use. The land may or may not be used for grazing and it may or may not, usually not, be allowed to revert to forest or woodland. The basic problem in trying to define the farming system of the upland areas is that it is not systematic. Some parts of the land, the banana gardens for example, will remain in almost continuous cultivation and be fertilised by the addition of domestic refuse and trash resulting from the cultivation of nearby crops. Other parts of the land may be cultivated only for a few years at one time and then allowed to revert to scrub - a very rapid process in some areas where cultivation does not include the clearance of all the natural cover. Other areas consist of partially cleared or uncleared woodland planted with bananas and food trees. Still other parts are cleared for only one or two years and are then grazed in an unsystematic way.

The pattern of cultivation in St. Catherine is by no means common to the rest of Jamaica but is typical of the higher, wetter areas in the eastern part of the island. Thus if a classification of the non-plantation agriculture for the whole island were to be drawn up it would present many difficulties. The Census of agriculture avoided these problems since it defined land use purely in terms of what each individual plot was being used for in the census year. Unfortunately, because an attempt is being made to correlate land use with soil erosion, it is of little value to know what happened on a single small-holding field in one particular year; what is required is knowledge of the long-term land use pattern. The plantations pose no such problem since the fields are in almost continuous use and normally with the same crops. A further problem of interpreting the nature of the land use on each individual field is that in the upland area they are often too small to plot on a map. An individual field will often be as small as 20 metres square or less. What needs to be considered, therefore, is the general pattern of land use in these areas since, in this way, account may be taken of the annual changes in use between the different parts of the same area. Unfortunately this more generalised approach to the land use of the upland areas, while giving a more realistic impression of what is happening, does not allow for a direct comparison with the Census data.

This still leaves the problem of how to define the actual land use in these areas. Mapping organisations, such as the Directorate of Overseas Surveys, would be content to describe the areas as woodland and scattered cultivation. This would be regarded as being too imprecise from the point of view of a Geographer or an Agriculturalist. The choice is basically between the term 'shifting cultivation' or one of the terms like 'fallow system' or 'rotation system' coupled with cultivated woodland. Shifting cultivation has the advantage that it implies a non-systematic pattern of land use which seems to be the rule, at least in some parts of the island, and it is also the term employed by Ahmad (1977) who is the one authority who writes specifically about the West Indies. On the other hand, most of the authorities would preclude systems where there is registered title to land and where, after about three years of cultivation, the farmer may return to the same plot within seven years. The other possible definitions are similarly defective in that they try to systematise something which, in Jamaica, seems to be characterised by a lack of system. It is with great reservations that the term 'bush fallow' has been chosen to characterise the field cultivation system of the upland regions. It is felt that this term indicates that there is a system of rotation being practised, but makes no definite assumptions concerning the relationship between the length of the period of cultivation and the length of the period of fallow. The term does not make assumptions concerning the use of the fallow land, except that there is a tendency to allow it to revert to bush or natural vegetation.

This use of the term 'bush fallow' is in broad agreement with Boserup (1965) and Harnapp and Knight (1971) although it should be noted that the latter may prefer to designate land use according to 'phase'. Phase for Harnapp and Knight (1971) is 'a means for determining the time sequence of human activities and growth stages of vegetation both in agriculture and in the "natural" landscape'. Hence an annual cropping system would show a 'uniform phase', tropical forest would have 'no phase detectable' and bush fallow would be termed 'progressive-cyclical'. There are advantages to this type of classification since, in theory, the term will mean the same to all workers in the field and thus avoid the confusions that can arise from the use of terms like shifting cultivation, but it is felt that this type of terminology will not find ready acceptance from the practising agriculturalists. It has been decided, therefore, to retain a more traditional terminology for this project.

Complicating the whole pattern is the uneven distribution of land. Although with most features of the agriculture it is dangerous to draw hard and fast rules, it would seem that those areas in woodland form parts of large holdings from which an adequate livelihood can be made without recourse to wholesale forest clearance. These areas would normally be used only for coffee, cocoa or banana cultivation since these crops either need the shade of large trees or, like bananas, can tolerate shade.

The problem for anyone studying the pattern of cultivation, either on the ground or on aerial photographs, is that there are no clearly defined property boundaries which would give some indication where a large holding in woodland ceases and where a smaller holding starts. This is one of the reasons why it is extremely difficult to obtain an accurate estimate of the amount of small-holder land cultivated each year. It could well be that in areas where only 10% appears to be used there is in reality very little small-holder land present. Hewitt (1979) has stated that most of the apparent variation in the amount of land cultivated each year in the upland areas is due to the different patterns of land tenure and not to differences in land use between different small-holders. He further stated that the normal cycle for small-holder cultivation is three years of cultivation followed by six or seven years of fallow. Thus 30-40% of small-holder land should be in cultivation in any one year and where the amount of cultivated land falls much below this there must be areas of permanent woodland being used for the cultivation of coffee, cocoa or bananas. Figure 4.1 shows different patterns of cultivation, which are due to the land tenure pattern, in areas of similar soils and topography.

The interpretation of these areas on the aerial photographs is relatively easy since the cultivated areas are quite distinct from the surrounding woodlands. The chief problem lies in deciding where the boundaries are, between the areas that contain such small patches of cultivation that the whole area could be considered as woodland, those areas in which woodland and cultivation are of more or less equal importance, and those areas where cultivated land contains small insignificant patches of woodland. What is being dealt with is a continuum from pure woodland through to pure cultivated land, although the extreme ends of the continuum rarely exist. Any division of a continuum is, at best, arbitrary and in this case it is complicated by the nature of the land use. The cultivated land is more important than the woodland from the point of view of soil erosion, large areas of land are 'cultivated land' but in bush fallow at any one time and this can sometimes be almost indistinguishable from scrub forest.

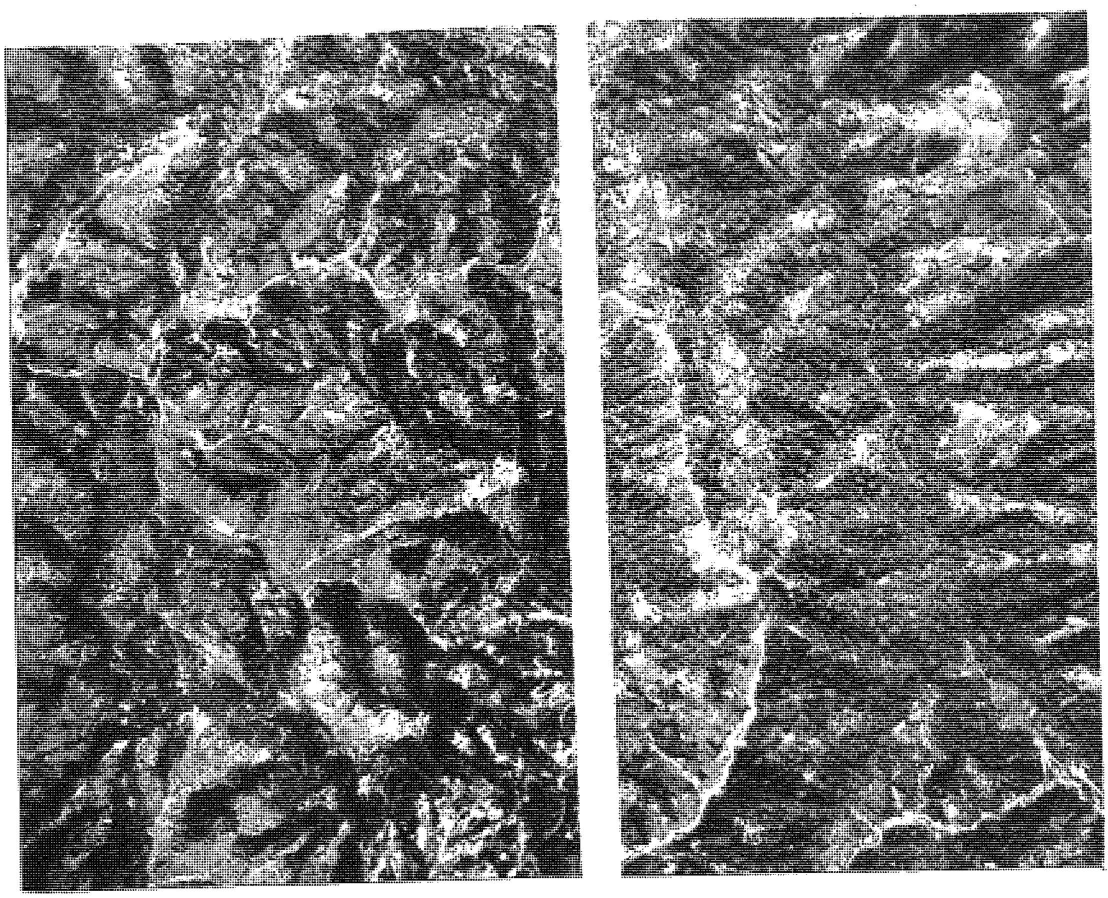


Figure 4.1 Two Areas of Similar Soils and Slopes Showing Variations in the Land Use Pattern due to Differences in Tenure.

This is especially the case where there are food trees or economic trees, such as pimento, which would be left by the farmer even when the land is cleared for cultivation. For these reasons any area with more than 20% active scattered cultivation was interpreted as 2f/6 (mixed cultivation and woodland) or 2f/7 (mixed cultivation and food forest). Where the cultivation accounted for less than 20%, but was either a patch of sufficient size or a close cluster of small patches, it was interpreted separately. This was more typical of the limestone areas where the bottom of cockpits are frequently cultivated (see figure 4.2). If there was less than 25% woodland present in an area of cultivation it was classed as mixed cultivation (2f). Although there were areas of pure stand or double cropping in the small-holdings of the lower, flatter areas; in most cases the small-holdings of the hilly, marginal lands were used for multiple cropping or the individual crops cover too small an area to be separated.

There are two different types of woodland recognised by the Census of Agriculture (1973, 74) and it was felt that, wherever possible, the classification used should conform with this. In the definitions given in section 4.2 above it was noted that woodland consisted of areas of trees the economic value of which lay in the timber rather than in any fruit or other product. Foodforest consists of areas of trees whose primary economic value lies in their fruits. Unfortunately it is not possible to clearly distinguish between the various types of trees when viewed on medium scale photography. In some areas, for example those characterised by thin limestone soils, the single, low canopy nature of the woodland precludes it from being foodforest. In most areas, however, the

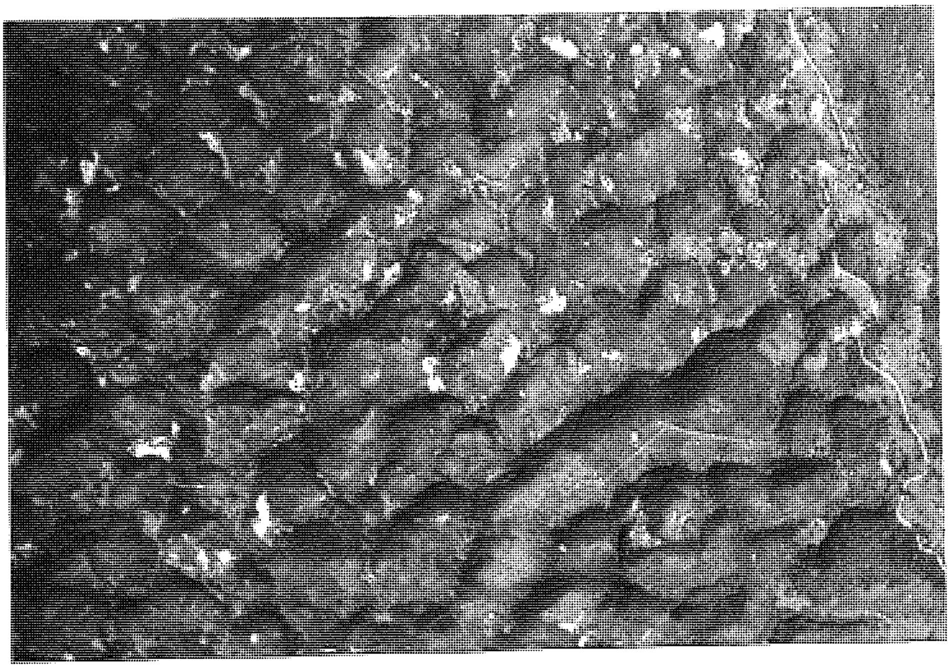


Figure 4.2 Limestone area North of Lluidas Vale Showing Cultivation of Cockpit Bottoms.

interpreter is dependent upon a single species common to most areas of foodforest - the coconut. The characteristic radial pattern of the canopy is extremely distinctive even on medium scale photography enabling even solitary trees to be identified. The coconut as a source of oil is an extremely important tree to the economy of the small farmer and is found throughout the study area in association with all forms of cultivation and foodforest. Since the photography was taken in 1968 the whole area has been afflicted by 'lethal yellowing', a disease of the Jamaican Tall species of coconut. The fronds turn yellow and fall off and the tree dies leaving a trunk which may stand for several years. Undoubtedly this would make the identification of foodforest areas much more difficult on more recent photography but it has not, as yet, been possible to evaluate to what extent.

Economically the most important land use types in the study area are the extensive cultivated areas occupying the flat fertile lands of the Lluidas Vale and St. Thomas in the Vale. In the main it is possible to define these lands as plantation, in pure or mixed stand. The problems arise when a definition is attempted of the smaller holdings, often on the edge of the plains, where the crops are in pure or mixed stand, and the holdings are too large to be classed as small-holdings. Ruthenberg (1976) attempts to avoid the issue by defining land use according to the cropping system applied. He does use the term plantation, but uses it to define 'any land that is planted with perennial crops....provided it is large in area and operated by a planter or manager commanding a large number of paid workers'. By this definition a number of the estates taken out of private hands by the Jamaican Government, and now worked as co-operatives by the workforce, would no longer qualify as plantations despite being visually indistinguishable from traditional plantations. Likewise the 'plantations' of Barbados would not qualify for the designation since the sugar is normally replanted after each harvest rather than being allowed to ratoon. The sugar is thus grown as an annual rather than a perennial crop.

Waibel (1933) defined a plantation as 'a large-scale agricultural and industrial enterprise, producing high value vegetable products, usually under the management of Europeans, and involving great investment in labour and capital equipment'. This definition is unsound for a number of reasons. The chief reasons being that not all plantations are also industrial enterprises, not all plantations are under European management and not all are both capital and labour intensive, some are only one or the other. It can be argued that a plantation that does not carry out at least the initial processing of its produce has ceased to be a plantation and should be perhaps just termed an estate. Nearly all the plantations in Jamaica had their own factories until perhaps one hundred years ago, but with increased cost most of the factories closed and processing is now carried out in a few centralised factories. Have the estates which no longer have their own factories ceased to be plantations?

Manshard (1974) suggests a minimum size of 50-100 hectares (120-240 acres) for a plantation and in addition that the main purpose of the enterprise should be production for markets, either internal or export. He further states that 'technical-industrial installations' must exist to prepare the produce for marketing. Gerling (1954) did not believe that industrial features were necessary to a plantation, merely that it should be a large-scale enterprise producing tropical or sub-tropical raw materials.

This definition would certainly accord well with the situation in Jamaica, but it still leaves the problem that if the same crop is being grown the actual cultivation techniques are the same whether the field is part of a 10,000 hectare estate or a 25 hectare farm. On farms of less than about 20 hectares there will rarely be large areas given over to a single cash crop, or pair of crops such as coconuts and bananas. All fields exhibiting monoculture or intercropping of two staples have therefore been designated as 'plantation' land if the fields exceed one hectare in size. Field observations were able to confirm that most cropping of fields in excess of one hectare conformed to the plantation type. Since the main concern of this research is the relationship between land use and erosion this definition has proved adequate, but should it be extended to include ownership and size of holding it would have to be considerably revised. The remainder of the cultivated land in the flat parts of the study area was classed as small-scale cultivation (2) and subdivided according to the dominant crop. It was thus classed together with the small-scale farming in the hilly marginal lands. Such a grouping is justifiable since the methods of cultivation are common to both even if the environments are different.

Grassland, both improved and unimproved, posed no great problem either in definition or in identification. They are not, however, synonymous with pasture and are, therefore, normally found only on large estates as/most pasturing by small-holders is carried out on fallow fields. Figure 4.3

shows an area of pasture between Bog Walk and Wakefield being used for the grazing of one of the Jamaica Hope breeds of cattle. This particular area was still in cultivation on the 1968 photography but apparently suffering from gullying. At some point it must have been found that the problem was too severe for it to remain in sugar and the decision taken to use it as pasture.

Apart from the areas of grassland associated with the large estates there are a number of areas in the limestone cockpits which are used for grazing. These would appear to be areas of permanent grassland rather than fallow. On the photography grassland can usually be distinguished from fallow as no attempt is usually made to control herbaceous and other species of plants unsuitable for animal consumption. In areas of permanent grassland these species are generally destroyed to preserve the quality of the pasture. This leads to most areas of grassland having a far more even texture than areas of fallow. Improved grassland will normally have a more even texture than unimproved grassland. The one possible area of confusion lies between sugar cane soon after rationing and grassland. Where the cane is being grown in large fields with cane breaks there is no real possibility of confusion, but there are areas of cockpits adjoining both Lluidas Vale and St. Thomas in the Vale where there is both cane and grassland. As the cockpits are rarely much over two or three hectares cane breaks are not necessary and the problem of interpretation becomes more difficult. As the cane becomes more mature the problem decreases since it becomes possible to observe the height differences between the cane and grass. At the earlier stage the only clues are slight differences in tone, the rather more even texture of the cane and possibly

Figure 4.3 Improved Pasture Between Bog Walk and Wakefield.

some signs of cultivation patterns. The ruinate class used by the Agricultural Cenus of Jamaica is a rather ambiguous class since it seems to imply what is normally described as 'bush fallow' rather than land which has been ruined for agriculture. This is emphasised by the exclusion of extremely steep or rocky land of no agricultural value. There was an area in the north-east of the study area, which due to its extremely dissected nature and low apparent agricultural value, was interpreted as ruinate in an initial study of the area. It was found that on a study of both sets of photography i.e. 1961 and 1968 that generally the apparently ruinate land on the earlier photography was back in use by 1968. Obviously some areas had deteriorated still further by 1968 but few areas identified as ruinate on the earlier set had not either been returned to agricultural use or showed signs of a 'healthy' regrowth of 'natural' vegetation. Subsequent field examination and discussion with agriculturalists on the island confirmed that what the Census defined as ruinate was, within the definition of this work, the fallow stage of the bush fallow cycle. Although considerable areas of land unsuitable for agricultural use could be identified these were explicitly excluded from the definition of ruinate by the Census.

The fallow classification used by the Census is, like the ruinate, unsuitable for use in the current research. While it is certainly of value for the Census to know how much land is being 'rested' at any one time, this project is more interested in what the land is being used for when it is in use. Normally it is a relatively simple process to determine the purpose for which fallow land has or will be used. In most plantation the only fallow land is land upon which sugar is normally grown and which is between plantings. In the small-holder areas the fallow land would normally be land that has been taken out of cultivation to recover its fertility. Since it is part of the bush fallow cycle it is classed as cultivated land although not at present being cropped. This is necessary when examining the relationship between land use and soil erosion. It could well be that a large percentage of the land found to be suffering from erosion was, at the time of mapping, fallow. This might tell a great deal about why it is fallow but would say nothing about what initiated the erosion. It follows that the land must be classified as cultivated land in order to obtain a sensible result from the analysis of the data.

The urban and industrial class forms part of the Census' 'other land' class but here has been treated separately.

CHAPTER 5

METHODOLOGY

To a large extent the methodology adopted for this project was determined by the constraints imposed by the data available on the area to be studied, and by the equipment available within the Remote Sensing Unit.

After a decision had been made that the research should attempt to build upon the work carried out in St. Catherine, Jamaica by Dr. W.G. Collins (1972) information was obtained from the Jamaican Survey Department on the availability of the latest air photo cover of the Parish. Although 1973 1:10,000 scale photography was available it covered only the south-east corner of the study area. The most recent complete coverage is at 1:25,000, flown in 1968. It was accepted that problems would arise at the field-work stage due to the age of the photography, but it was felt that any disadvantages would be outweighed by the financial advantages of using existing photography. When the project was first contemplated in 1977 the Jamaican authorities were considering having the whole island reflown to obtain up to date air photo cover, but even at the time of writing, over two years later, the various concerned bodies on the island have yet to agree on such matters as scale and the type of film to be used. It would seem, therefore, that the right choice was made when the decision had to be taken whether to use any existing photography, whatever its shortcomings, or to await new photography.

The equipment available within the Remote Sensing Unit dictated that the techniques used to interpret and plot the data were extremely simple. This again was not a disadvantage since the decision had been made to develop a methodology suitable for use in a developing country lacking access to the latest equipment. No equipment was obtained purely with this project in mind, although the Bausch and Lomb 'Zoom Transferscope' was obtained during the course of the project and was of great help in effecting the transfer of data from the air photographs to the base maps.

As it was originally intended to carry out a comparison between the erosion status of the land in 1961 and that in 1968, the 1961 photography was interpreted while waiting the arrival of the later photography from Jamaica. The interpretation of the 1961 photography proved very useful, despite the later change in the direction of the research which made the use of the 1961 photography unnecessary. It was during the interpretation of the 1961 imagery that all the major problems of definition and interpretation were experienced. When it finally arrived it was then possible to interpret very rapidly the 1968 photography. The interpretation was carried out once on the 1968 photography, and this was found upon checking to be sufficiently accurate to require only minor corrections or modifications. The total number of man hours involved in the land use interpretation was some 120, while the erosion interpretation which was carried out separately accounted for approximately 80 man hours. There were a total of 90 prints involved.

The procedure adopted for interpretation was to interpret alternate photographs in a strip and then, after the whole strip had been interpreted, to edge match between the interpreted prints. It was felt that although this approach would lead to extra work in checking where discrepancies arose, and making any necessary corrections to one or both prints, it would prevent the possibility of an incorrect interpretation on the edge of one print being transferred to the next print. For the same reason there was also no attempt to edge match between strips until after both strips had been fully interpreted. In most cases this procedure led to few problems and little additional work. Most of the cultivated areas had clearly defined boundaries as did the urban and industrial areas (8)

The problems arose when dealing with the boundaries between woodland and food forest, or between these areas and areas of mixed classification such as 2f/7 (small-holding, mixed cultivation and food forest). As was mentioned in section 4.3 it is often very difficult to determine whether an area of trees is food forest or woodland (within the definition of the Jamaican Census) and that coconuts were used as an indicator species. Figure 5.1 shows two areas of trees, one of which could be identified as woodland and the other as food forest. It will be noted that the canopy of the woodland is composed of smaller more regular crowns while the canopy of the area interpreted as food forest is composed of a greater variety of crown sizes and has an altogether rougher texture. Unfortunately these are almost 'extreme' cases. The woodland is an example of the vegetation on a limestone area and is characterised by a high degree of uniformity - figure 5.2 shows a ground photograph of such an area, showing a higher degree of similarity to the area of food forest in figure 5.1. Generally, however, most areas of trees identified on areas of limestone could readily be identified as woodland, and most areas of trees identified on non-limestone areas could be readily identified as food forest, without recourse to the use of coconuts as an indicator species. Figure 5.3 shows very clearly the sudden change in the vegetation across a boundary between an area of limestone and one of granodiorite.

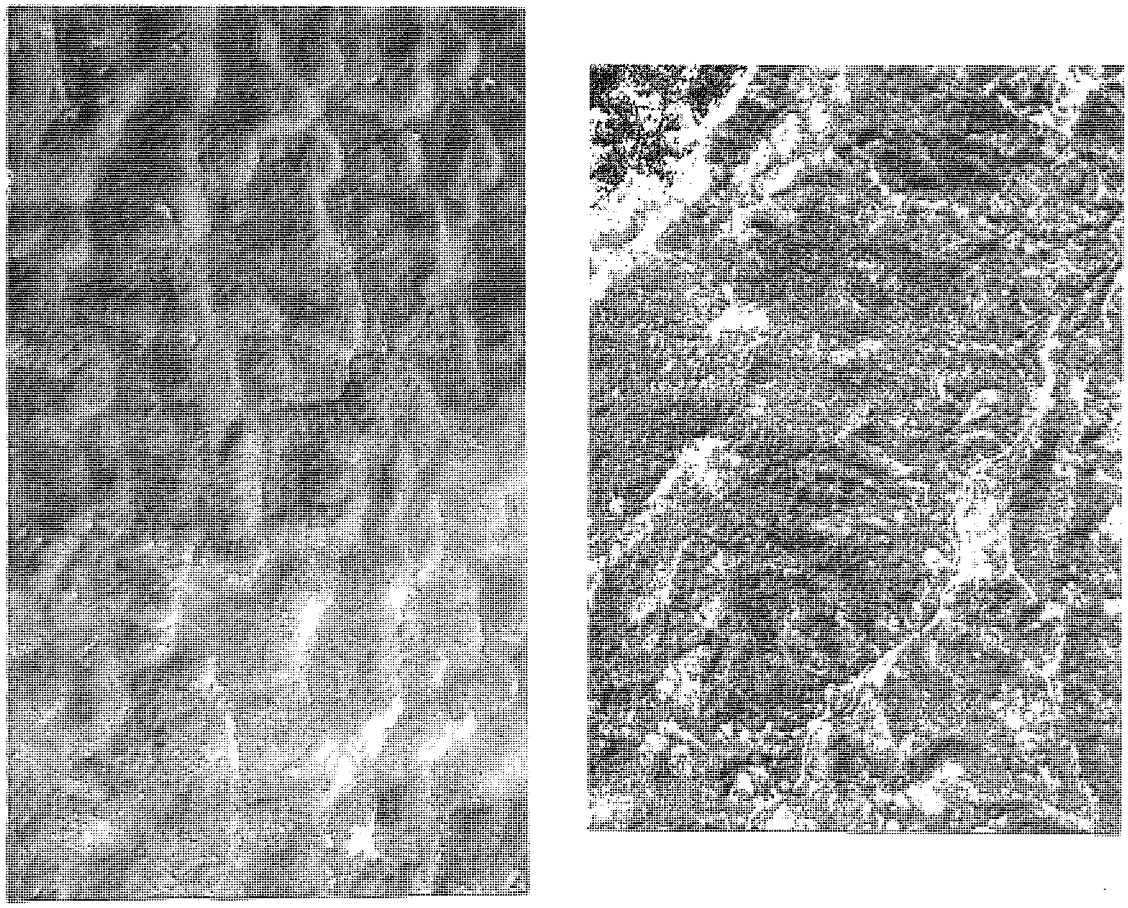


Figure 5.1 The Left-hand Photograph Shows Woodland (6) on Limestone, the Right-hand Photograph Shows Food Forest (7) on Granodiorite.

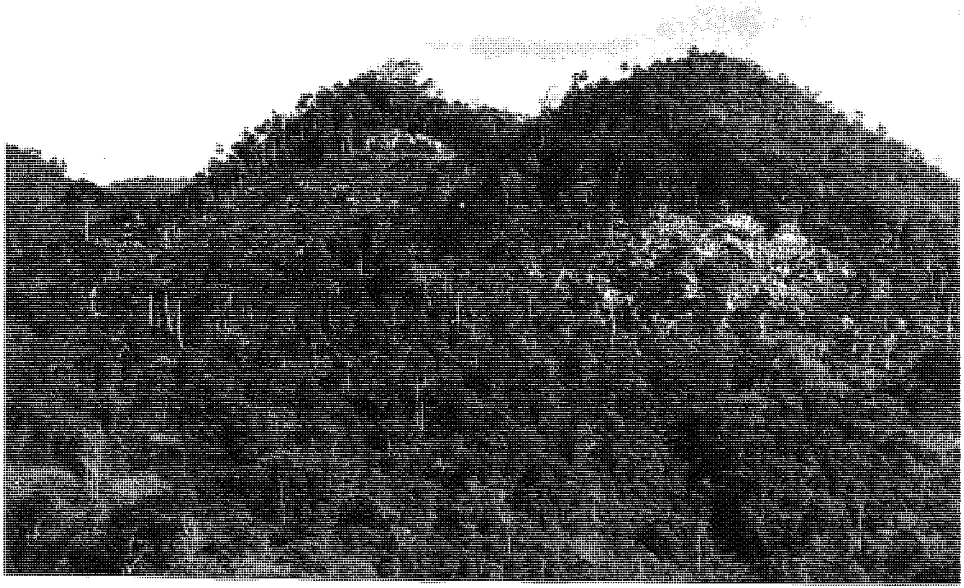


Figure 5.2 Ground Photograph of Woodland (6) on Limestone

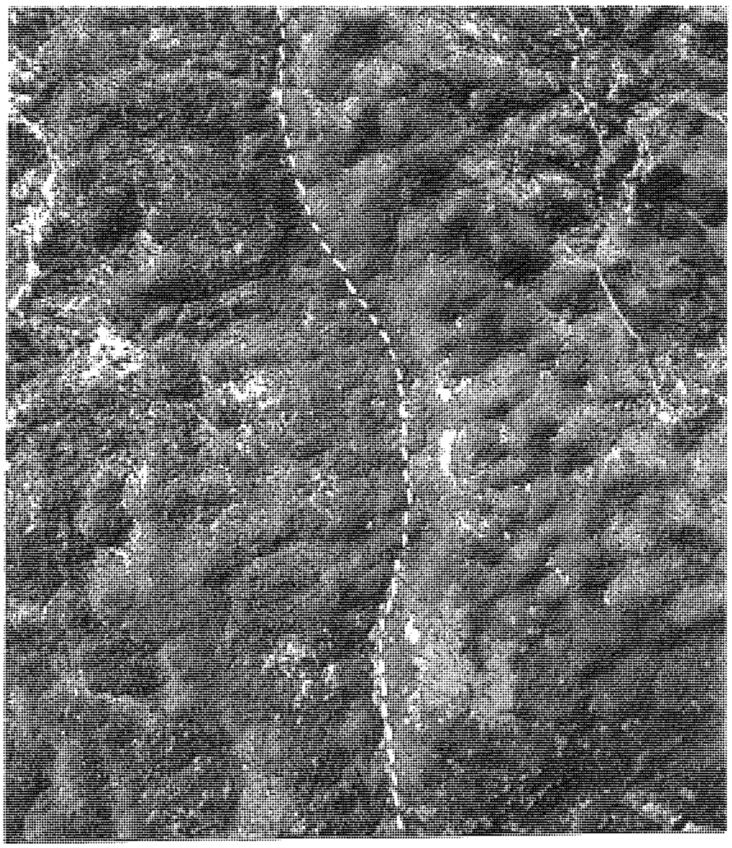


Figure 5.3 Air Photo Showing Vegetation Change Across the Boundary Between Limestone and Granodiorite (the pecked line marks the boundary).

The boundaries between mixed cultivation (2f), mixed cultivation and woodland or food forest (2f/6 or 2f/7) and woodland or food forest (6 or 7) were drawn to conform as closely as possible with the definitions given in section 4.3. A degree of subjectivity was allowed at this stage as it would have been extremely time consuming to make measurements of each area to determine the precise ratio of mixed cultivation to wooded land. This would have been required to place a particular area within 2f, 2f/6 (or 2f/7) or 6 (or 7). Where there was doubt a visual check could be made against measured areas to determine to which class the area belonged.

Most of the land use types and the crops to be identified could be readily determined using x3 magnification on the Wild ST4 which was used for the bulk of the interpretation. The identification of bananas could not, however, be made using x3 magnification and for this x8 would normally be used. The procedure was that any cultivated areas for which the crop type could not be determined using x3 magnification were marked with a question mark on the trace overlays; these areas were then viewed separately using x8 magnification, or occasionally using the Zeiss 'Interpretoskop' which can give up to x14 magnification. Normally this would allow a positive identification of bananas to be made.

All interpretation was made onto melinex trace overlays using pens designed for use with overhead projectors. These pens could not be used for more than about twenty overlaps as they rapidly gave thick lines if used for longer. Unfortunately the overlay material used, having a hard shiny surface, was not suitable as a drawing base for waterproof ink. As the erosion interpretation was to be carried out on the same overlays using black TT ink, there was little alternative to the use of the overhead projector pens. An experiment was made using wax pencils but it was found that these often failed to give a satisfactory line, and the lines would rapidly degrade with normal handling of the overlays.

The photographic characteristics of the different types of land use have been dealt with in Chapter 4 and so need not be dealt with here. Appendix C gives examples of all major land use types, both as air and ground photographs. The interpretation of the soil erosion features on the aerial photographs posed rather more problems than the interpretation of land use. Chiefly this was due to there being few previous studies of soil erosion using aerial photographs, and most of those there are are either of the United States or of the semi-arid or arid tropics. The other areas covered included the seasonally wet tropics, but there appear to be no studies of areas such as Jamaica where there are two 'wet' seasons, one more marked than the other. There is no really dry season in St. Catherine since the average rainfall per month is approximately 2 inches even in the three driest months. The evaporation rate from a class A pan is approximately 4 inches per month during the driest months. Although this would indicate a soil moisture deficit during these months, the annual surplus of rainfall over evaporation of approximately 5 inches would indicate that, although vegetal growth would be inhibited during the dry season it would not actually be stopped. The figures given above are drawn from Worthy Park where the lowest rainfall figures for the study area are recorded. The north-east of the study area, for which figures are not available, would almost certainly not exhibit such a moisture deficit. It could be argued, therefore, that within the study area plant growth would be continuous throughout the year. Field observations bear out this argument, since even towards the end of the 'dry season' there were no marked signs of an increased rate of leaf shedding by trees nor a marked increase in yellowing of grasses. This means that there is no period, such as after spring ploughing and before new growth starts, when the ground is clearly visible on the aerial photographs. Semenova (1960), Bergsma (1970) and Jones and Keech (1966) all worked in areas showing marked seasonality in the climate and hence in the rate of vegetation growth and, although they provide useful indications of the way to proceed with erosion interpretation, they cannot be taken as guides with respect to the appearance of erosional features on the aerial photographs.

This is unfortunate in the case of Bergsma (1970) since this is a useful guide to most other environments. The list of signs evident in the field where accelerated soil erosion is occurring applies equally well in all environments, and so is shown in Table 5.1, but the correlation and comparison with the evidence visible on aerial photographs is of rather less use.

<u>TABLE 5.1 Indications in the field of the presence of accelerated erosion (after Bergsma, 1970)</u>

1. Muddy Streams
2. Low, poor or absent vegetation
3. Flow patterns on the ground caused by the runoff
4. Coarse particles washed free on the surface
5. Subsoil colour bare
6. Bare rock
7. Tree roots exposed
8. Sedimentation in flat areas

9. Gullies and rills
10. Field boundary pattern disrupted, no inhabitation, land dissected, badland topography
11. Overflow patterns along streams
12. Stream banks with vertical scarps, sometimes with gullies

Table 5.2 represents the type of features Bergsma believes identifiable on 1:10,000 to 1:20,000 photography. Most of them, if not all of them, would be equally identifiable on the 1:25,000 scale photography used in this project were it not for the complicating factor of the vegetal cover being more dense within the study area than in the areas studied by Bergsma (1970 and 1974). Jones and Keech (1966) in their work in Rhodesia used 1:25,000 photography to identify soil erosion problem areas. They were chiefly concerned with gully erosion, having satisfied themselves that there was a 'sufficiently close correlation between the degree of sheet erosion and rill erosion and the degree of gully erosion'. Certainly gully erosion is sufficiently clear to allow for easy interpretation even in Jamaica, but there does not seem to be the same close relationship with sheet and rill erosion that exists in Rhodesia. Certain areas, the granodiorite areas provide a good example, exhibit rill and sheet erosion and minor land slips but do not generally exhibit gully erosion. This could be due to preventative measures or the soil condition, but in either case to use gullying as the main or sole indicator of the presence of rilling or sheet wash would be equally misleading.

In the study area chosen the presence of accelerated erosion is indicated on the aerial photographs by different image characteristics, depending on soil type, topography and vegetation. Table 5.3 gives a general breakdown of the charact-

TABLE 5.2 Erosion Features on Aerial Photographs (after Bergsma, 1970)

Process	Erosion Features	Interpretation of	AP Image Shows
Sheet Erosion	Layer of soil removed from land, local deposition	Tone, very low vegetation position	Indications
Rill Erosion	Rill pattern	Tone, texture, position	Indications
Gully Erosion	Gullies	Tone, position, relief, vegetation	Good image
River Bank Erosion	Steep banks in outer curve, slump scars, bank protection measures	Tone, position, micro-relief	Indications
Flooding	Destruction of vegetation and fields, channels and deposits in a flow pattern	Tone pattern, land use pattern, micro-relief	Good image
Mass Movement	Lands	Relief form, micro-relief	Good image when recent

istics of eroded land for each of the main soil complexes within the study area. In general erosion features were more easily observed in limestone areas than in the other areas. There would seem to be a number of reasons for this. First, and probably most importantly, this would seem to be due to the soil being very shallow, even under 'natural' cover. When soil erosion occurs, especially on steep slopes, most of the soil can be removed in a single wet season exposing the bedrock. Even if no further erosion occurs plant regeneration will be extremely slow, and even then it will be restricted to the cracks and hollows in the limestone surface where some soil remains. This leads to the characteristic appearance of an eroded limestone area where there is an extremely pale image caused by the high reflectivity of the bare, or nearly bare, limestone surface. Vegetation is very patchy or almost non-existent. This appearance persists for many years.

On the alluvial and interior basin deposits, Lluidas Vale, parts of St. Thomas in the Vale and the lower courses of the Rios Pedro and Doro, the dominant forms of erosion are bank erosion and gullying, initiating from the steep banks of the rivers. In many cases bank erosion can be inferred from the steepness of the banks and their lack of vegetal cover. In a number of areas, however, bamboo has been planted to stabilise the banks and the dense canopy of the bamboo does not allow the present state of the bank to be assessed. The matter is further complicated in areas such as the banks of the Rio Cobre in Lluidas Vale, where the river is sufficiently incised below the level of the Vale as to be undercutting the bamboo (see Figure 5.4). The gullies could be readily identified and an assessment made whether they were active or not, based on the steepness of the sides, the sharpness of the edges

Figure 5.4 Undercutting of the Bamboo Planted to Control Bank Erosion of the Rio Cobre in Lluidas Vale.

TABLE 5.3 Soil Erosion Interpretation Elements Visible on 1:25,000 Photography for Different Soil Types

Soil Type	Macro Relief	Micro Relief	Vegetation	Soil Tone
loams over Granodiorite/Andesite	steep sided, narrow valleys	sharp edged features	low and patchy	pale, blotchy or streaked
soils over alluvial and interior basin deposites	broad, gently sloping valleys (polje)	some gullying, bank erosion	patchy growth of crops, especially sugar	pale blotchy
soils over limestone	cockpit topography	erosion limited to steep cockpit sides	thin or non-existent if erosion severe	very pale, mottled white specks of bare rock usually visible
soils over conglomerate shales etc.	steep sided narrow valleys	sharp edged features high density of drainage channels	low and patchy	pale and blotchy

and the condition of the vegetation. The loams over the granodiorite/andesite and the soils over the conglomerates, shale, etc., can be treated as a unit from the point of view of soil erosion, since the forms erosion takes on these groups are very similar. Sheet wash would appear to be the dominant form of erosion on these soils, there being very little evidence of gullying; although bank erosion can be observed in some areas. The chief indicators of the presence of erosion are a pale, blotchy appearance of the soil and low or degraded vegetation. On longer slopes subject to sheet wash it is possible to observe streaks running down the slope, indicative of the presence of rills. Some slumping can be observed but although it is quite common in ground observation only fairly large slippages were visible on the aerial photographs.

Since work was earlier carried out on the 1961 1:25,000 photography it is possible to make a comparison between this and the 1968 cover used for the project. The 1961 cover was printed as low contrast photography as it was printed in an electronic printer by Hunting Surveys. This process, called dodging, produces an even toned image to enable maximum detail to be observed, even in very light or dark areas on the image. The 1968 cover, which was printed by the Jamaican Survey Department, is very high contrast since the imagery was not 'dodged' during printing. Although the resulting product appears poor by comparison with the 'dodged' 1961 photography, it soon became evident that for the interpretation of soil erosion it was far better. The wider range of grey tones plus the very pale tones available on the undodged prints enabled problem areas to be rapidly identified. It would appear from the work that although there is little gain in accuracy in using high contrast prints, the real gain is in the rate at which interpretation can be carried out. It is however possible that a semi-skilled interpreter would be able to obtain a higher rate of correct identification on the high contrast photography. This would be important if a large area had to be mapped using inexperienced interpreters. The best time to obtain the photography would be during the dry season, although as has already been noted there is not a completely dry season in the study area. During the dry season the vegetation will show the greatest variation due to depth of soil, and provide least ground cover. Unusually in the world of aerial photography this is also the best time to obtain good cover. The usual pattern is that when ground conditions are at their optimum atmospheric conditions are at their worst for obtaining good photographic cover.

A brief assessment was made of the infra-red colour photography taken of part of the area by the National Aeronautical and Space Administration (NASA) in 1971. This photography was taken as part of a LANDSAT simulation exercise using high altitude aircraft. The resulting photography was produced at 1:50,000. This scale would probably have been too small for the project anyway, but in the event the quality of the imagery was so poor, due to a combination of poor photography and processing, that it was of no value in carrying out a comparison between panchromatic black and white photography, and infra-red false colour photography.

After all interpretation had been completed, checked and edges matched the data was transferred onto transparent overlays on 1:12,500 topographic maps using the Bausch and Lomb 'Zoom Transferscope'.

This instrument proved to be extremely quick to operate and provided good illumination of both photographs and maps. The zoom facility enables rapid localised fitting to be obtained between photograph and map, especially in the steep, broken areas. Other instruments would probably have proved as good in the flat areas but it is doubtful if mapping could have proceeded as rapidly in the hilly parts of the study area. The instrument used is illustrated in Figure 5.5. Both the land use data and the soil erosion data were transferred onto the same overlays to avoid problems of misregistration at a later stage. Unfortunately the overlay material used was tracing paper, and although it was realised in advance that dimensional stability could prove a problem it was found that dimensional stability was even worse than anticipated. From hindsight it may appear that it would have been preferable to use polyester or polyvinyl film for the overlays, but this would have proved expensive and it was felt that the stability of tracing paper would be closer than film to that of the paper maps. In fact there seems to have been an initial change in the dimensions of the tracing paper and then very little alteration. Perhaps if the paper had been cut into sheets and then left to condition flat for a few weeks the problem may have been avoided. A further problem was encountered when the maps and overlays were taken to Jamaica for field checking. The great change in temperature and humidity effected large dimensional changes in both maps and overlays, but more in the overlays than in the maps. When brought back to Britain at the end of the field work it seems that the overlays did not return to their pre-Jamaican dimension. Data on the changes in the dimensions of the maps and overlays compared with the original map format is given

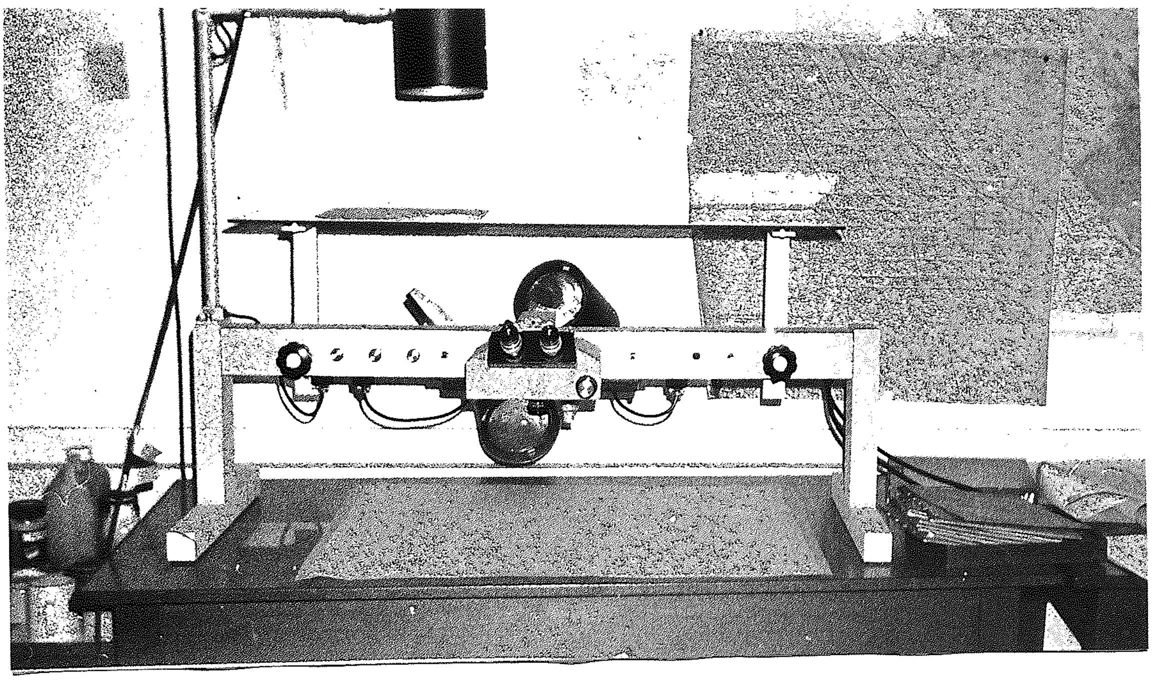


Figure 5.5 The Bausch and Lomb 'Zoom Transferscope'.

in Appendix D. Since this study involves relative differences rather than absolute values, and it can be assumed that any changes within an overlay will be constant, there should be little error in the computation of the results. Where there is a potential source of error is in obtaining the values of the slopes, which come from the base map. It is possible in areas of widely different slopes to obtain erroneous values for the slope of eroded land. This is not such a problem with the correlation between land use and slope since only average slope classes were used.

The soils data was obtained from copies of the original 1:12,500 soil survey field sheets. In addition to the soil numbers (Appendix E) these also showed the slope classes (Table 5.4) and the erosion status (Table 5.5).

TABLE 5.4 Slope Classes used in St. Catherine Soil Survey (after Vernon and Jones, 1958)

Slope Class	Slope Gradients
A	$0^{o}-2^{o}$
B	$2^{o}-5^{o}$
C	$5^{o}-10^{o}$
D	$10^{o}-20^{o}$
E	$20^{o}-30^{o}$
F	Over 30^{o}

TABLE 5.5 Erosion Status Classes used in St. Catherine Soil Survey (after Vernon and Jones, 1958)

Soil Erosion Class	Soil Erosion Condition
+	Area of accretion
0	No apparent accretion or erosion
1	Slight erosion
2	Moderate erosion - approximately 50% of top soil lost
3	Severe erosion - all top soil lost and some subsoil lost
4	Very severe erosion - all top soil lost and most of subsoil lost
5	Extremely severe erosion - eroding parent material

In the initial stages of this project no attempt was made to use the soil erosion data, it would anyway have been out of date, but it was used as a check to see if the pattern of erosion had changed appreciably since the middle 1950's. As the original soil survey had been a mixture of air photo interpretation and extensive field work it was felt that the recommended land use for each soil/slope combination would prove a good check on the results of this project.

The Land Capability Classification of the soil groups and slope classes and the recommended uses are all given in Appendix F.

CHAPTER 6

FIELD CHECKING

6.1 Introduction

All field work was carried out in St. Catherine, Jamaica between 17th January and 23rd March 1979. This period was chosen because it afforded the highest probability of dry weather which would allow the field work to go forward in a planned way. Although the temperatures were in the range 25°C-29°C the lower relative humidity at that time of year made field work more comfortable.

A number of factors contrived to make field work more difficult than it would have been in a more developed country. A lack of accommodation within the study area necessitated living in Kingston but, although this led to at least an hours journey both to and from most parts of the study area, it did mean that access to Government Offices, the University and the libraries was good. A more serious drawback was the nature of the roads within the study area. In conversation with officials on the island it was learnt that since the onset of Jamaica's financial troubles there had been a marked deterioration in the condition of the roads due to a lack of both money and materials to maintain them. In the limestone areas and, to a lesser extent, in the alluvial areas this has not caused too much of a problem, but in the granodiorite/andesite and sedimentary areas of the north and north-east the roads have deteriorated such as to make them practically impassable to all but four-wheel drive vehicles with good ground clearance. Unfortunately such vehicels are not available for hire in Jamaica. That a reasonable amount of field work was carried out owes much to the Commissioner of Land Valuations, Mr. St. Clair Risden, who, whenever possible, made a Land Rover and driver available. In all he was able to make a vehicle available for thirteen days during which time a series of traverses and detailed studies of a number of areas were carried out. A number of trips to more accessible areas were also made by car, so that in total approximately twenty days field work were completed during the period on the island.

The field work was divided into two phases; in the first a series of traverses were made across the study area checking the air photo interpretation of the land use and erosional status along the line of all roads and tracks. Although this may seem an unrepresentative sample it had been noted on the aerial photographs that in most of the study area cultivation is restricted to within little over a half mile of a road or track. This is largely because the peasant farms are dependent upon stand pipes along the roads and major tracks for their fresh water for domestic use, there being few suitable natural sources of fresh water. This restricts settlement to the lines of these roads or tracks. Praedial larceny deters most of the farmers from cultivating an area too remote from his home to be readily protected. It was therefore felt that a series of traverses along the roads and tracks coupled with short traverses perpendicular to the main traverse lines would be adequate.

6.2 Description of Traverses

The lines of the traverse are shown in figure 6.1, the numbers indicating where short traverses off the main traverse line were made. Appendix G gives the soil and slope characteristics and lists for each of these points both the land use and erosional status, as observed on the ground and on the aerial photographs. Appendix G also contains an evaluation of the differences between the ground and aerial photographic

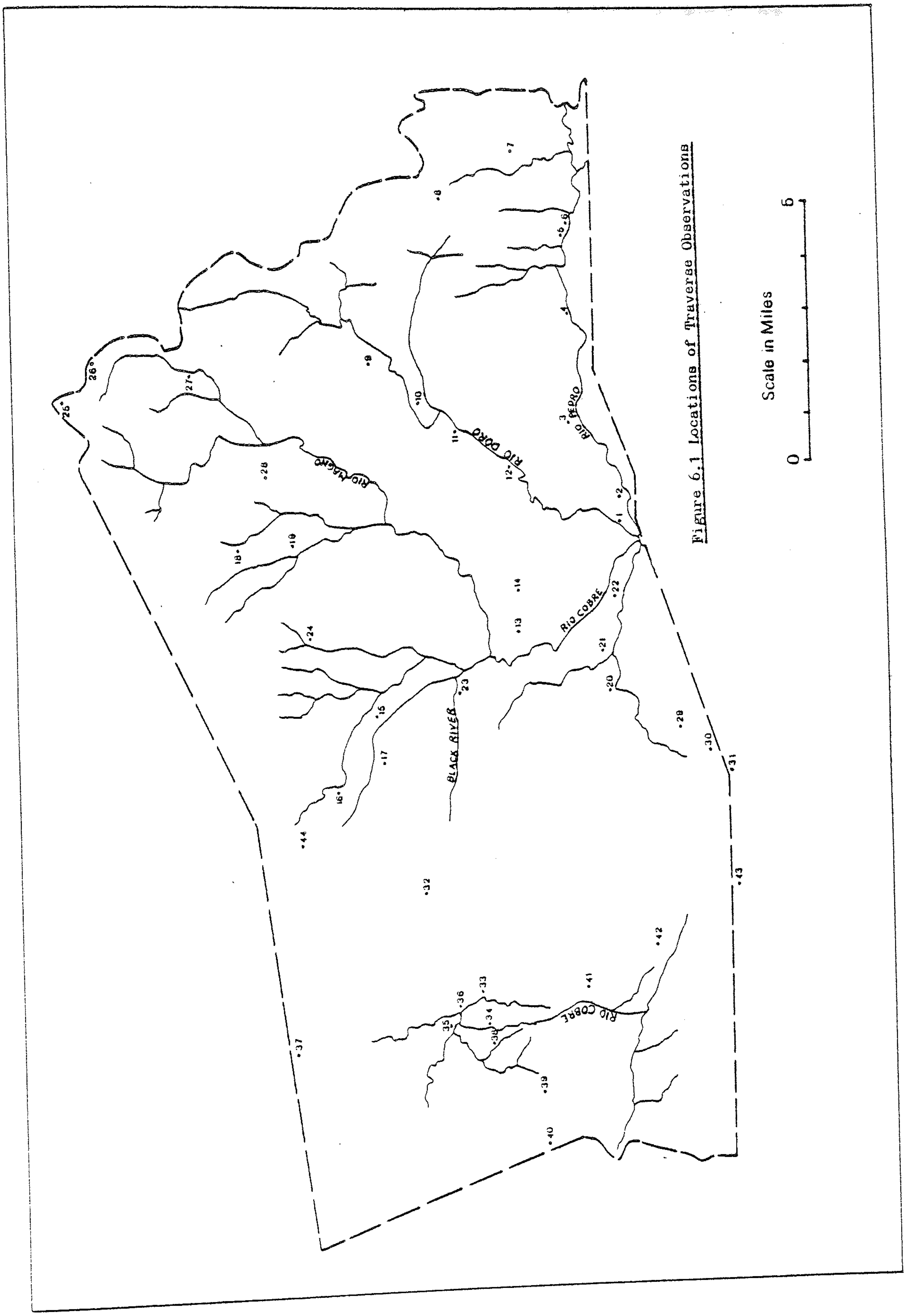


Figure 6.1 Locations of Traverse Observations

Traverses.

data. It is difficult to assess the percentage accuracy of the soil erosion interpretation since the number of samples is quite small and sampling was not carried out in a random way. Of the traverses made off the line of the roads or tracks only three discrepancies between air and ground data cannot be explained in terms of changes in the erosional status taking place between the date of photography and the date of field observations. In four cases the situation had improved and in three cases where there was no sign of recent deterioration it was possible to explain the failure to interpret the erosion in two cases. In one of them the area was covered by scrub at the time of photography, rendering the ground invisible; and there are no readily observable signs of degradation in the vegetation. In the other case a river bank subject to undercutting is obscured by the canopy of the bamboo planted to prevent bank erosion. It was noted during the field work that bamboo is the favoured plant species used to prevent bank erosion and headward erosion of gullies. If this had been known before the air photo interpretation was carried out it is possible that a number of other areas could have been identified where possible bank erosion was being obscured by bamboo. The distinctive canopy of bamboo allows it to be readily identified and it could well serve as an indicator of areas that may repay close inspection. The third area where an erosion problem was identified on the ground, but not on the photographs, is an area of sugar cane planted on sloping land (about 15^{o}). On the aerial photographs it appears slightly more patchy than surrounding areas of sugar but certainly there are no strong indications of an erosion problem. On the ground the cane appears thin and poor, and the soil surface appeared compacted and showed signs of high surface runoff. It is possible that the differences between ground and photographic observations is due to the time difference of the two sources and that there has been a substantial deterioration in recent years; however it is not possible to come to a definite conclusion. At all points where there were differences between the ground observations and the photographic interpretation a close study of the photographs was made to determine if there had been any error in the original interpretation. In all cases it was found that even in the light of the ground observations no changes to the original interpretation were needed.

Of the 44 side traverses inconsistencies were noted on ten which would indicate an approximate accuracy rate of 75%. However, only three inconsistencies could not be explained in terms of changes taking place between the date of photography and the date of field work. This would indicate that on recent photography a correct identification rate in the order of 90% could be expected.

6.3 Detailed ground studies

A second stage of field work involved the ground mapping of all erosion features in seven separate areas. As far as was possible areas representative of all the major physiological regions and major soil types were chosen. The location of these areas is shown in Figure 6.2. An assessment was made of the types of erosion present, the severity and the location of the erosion. These areas of erosion were mapped for comparison with the results obtained from the aerial photographs. Wherever possible enquiries were made of the local people to determine the age of erosional features if they appeared to be of recent origin. In areas of land rotation it was often established that fields showing signs of heavy sheet erosion

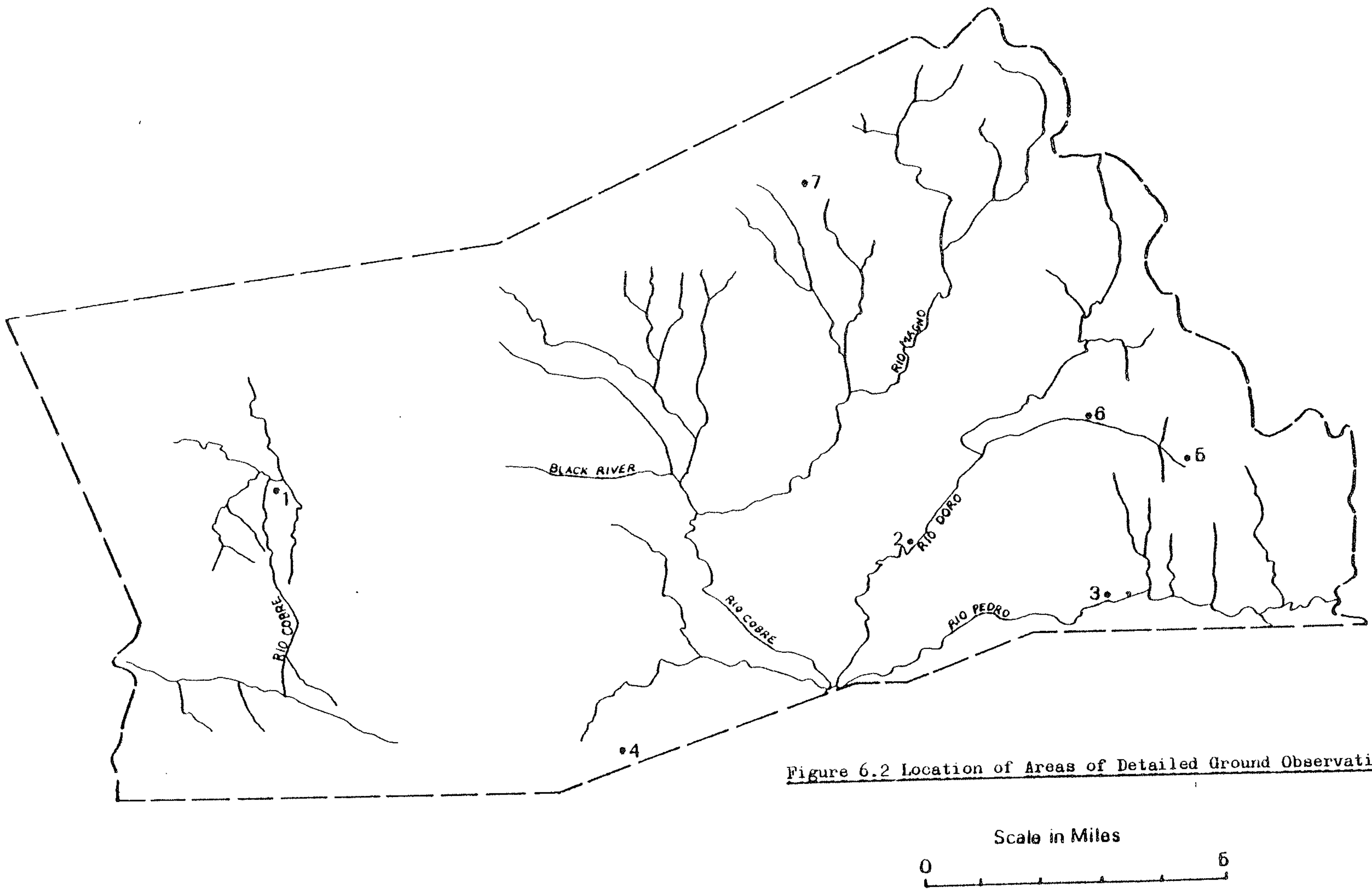


Figure 6.2 Location of Areas of Detailed Ground Observations

or slumping had been in cultivation for only one or two years. This was especially the case in areas of loam overlying granodiorite and andesite. The local farmers also stated that after being rested for five or six years they would be able to cultivate the land again as if the erosion had never happened. These statements support the view of Hewitt (1979) given in chapter 2. In the limestone areas it was possible to see almost bare rock slopes of about 40^{o} gradient which farmers reported to have been in cultivation three or four years earlier. Unlike in the granodiorite and andesite areas it is unlikely that these areas will support cultivation again within the lifespan of the current generation of farmers.

In the alluvial basins of Lluidas and St. Thomas (Areas 1 and 2, Figure 6.2) the most common form of erosion noted during the field work was bank erosion of the major rivers, especially the Rios Cobre, Doro and Pedro. Ground observations in these areas confirmed the findings of the traverses, that where bamboo had been planted along the course of a river there existed a high probability of an erosion risk. It was also observed that in many cases the bamboo was failing to control the erosion because the roots were insufficiently deep to prevent the rivers under-cutting the banks. Figure 6.3 shows an example of undercutting along the banks of the Rio Cobre in Lluidas Vale. Although it was possible to observe on the aerial photographs some patchiness in the growth of the cane in Lluidas it was difficult to confirm whether this reflected a real erosion hazard on the ground. The process of harvesting tends to break down any rilling within the fields making identification difficult. When the cane has been replanted and before the new growth is fully established, it is likely

Figure 6.3 Undercutting of the Bank of the Rio Cobre in Lluidas Vale.

Figure 6.4 Cane Planted Across a Drainage Ditch in the Rio Doro Valley.

that a problem exists, especially at the onset of the rainy season. During the period of the ground observations this was not evident because there was insufficient rain. Despite the widespread practice of burning the cane prior to harvesting, in most cases it would appear that sufficient trash is left on the ground to protect the soil from the direct impact of the rain. Thus in an area such as Lluidas, where more than eighteen years may elapse between replantings, the risk of long term loss of soil fertility is slight. A problem is posed by the practice of most estates in planting too close to water courses. In Lluidas and in St. Thomas in the Vale even the best managed estates planted with one half metre of the river bank. In St. Thomas places were observed where growing cane had been washed into the river. It also appears that little attention is payed to that maintenance of drainage channels. Despite the normal recommendations on the use of grass-lined ditches there seems to be an almost general policy, especially on the estates in St. Thomas to plant cane across the ditches (Figure 6.4). It was also noted that the general pattern is to cultivate the cane in rows up and down the slopes despite the Ministry of Agriculture recommendations to cultivate along the contour.

In the areas of loam overlying Andesite or Hornsfels (Areas 6 and 5, Figure 6.2) most of the cultivated land has slopes in excess of 20° gradient. Since most of the cultivation involves clean tillage there is a considerable soil erosion hazard. Figure 6.5 shows a field of sweet potato on a slope of 37°; the slumping evident at the bottom of the field is characteristic of much of the cultivation in this area. Figure 6.6 shows where the litter in a banana garden has trapped the sediment being carried down the slope by surface runoff. The sediment comes from the next field up the slope, where

Figure 6.5 Sweet Potato Planted on a Slope of 37°.

Figure 6.6 Banana Garden Showing Soil Having Been Washed Down from Higher Trapped by Ground Litter.

bananas are being cultivated using clean tillage. The slope here was about 35^{o} but within the banana garden, where the ground was covered by leaf litter, there did not appear to be much of a soil loss problem. The farmer had been cultivating this plot exclusively in bananas for many years, adding organic kitchen waste, without an appreciable loss of fertility or lowering of the ground surface. In other fields close by, the exposed roots of mature trees testify to a general lowering of the land surface. The heavy bed load of the streams also indicated that soil erosion was active in both areas, but the most striking feature was the rapidity with which the land recovers from soil erosion. This can only be due to the great depth of the rotted mantle overlying the parent rock. It would seem that for the foreseeable future there is unlikely to be any marked deterioration in the quality of the land in this area. The only real cause for concern is the rate at which silting-up is occurring in the Rio Cobre reservoir due to the heavy sediment load of the tributaries of the Rio Cobre.

In the area of clay/loam and clay overlying the white limestone (Area 4, Figure 6.2), most of the problems of soil erosion appeared to be due to lack of runoff control. Roadside drainage ditches were either inadequately maintained or absent, allowing water to concentrate on the roads and tracks and then spill over into adjoining fields causing minor gullying. There also seemed to be no provision for controlling runoff within the field thus permitting the runoff to form its own channels, again resulting in minor gullying. Surface compaction within the fields, mainly under cane, was aggrevating the problem by increasing the rate of surface runoff. In some areas limestone has been exposed and this has made cultivation more difficult.

In Area 7 (Figure 6.2) clay loams overly rocks of the Devils Race Course Volcanic series, where there is considerable evidence of past erosion. Large parts of the area have been colonised by bamboo, a sure sign of land which had been cultivated and then abandoned due to soil erosion and loss of soil fertility. The chief usage of the land at the present is as food forest. Among the trees, whose only value lies in their timber, it is possible to identify ackee, breadfruit, coconut, banana and pimento. Slopes which had been cultivated in the recent past show signs of minor gullying and slippages. These slopes are now covered with grass and low scrub which seems to have arrested the erosion. On a few slopes the bamboo is being burnt and cleared in preparation for bringing these areas back into cultivation. Although there is a greater erosion problem here than in Areas 5 and 6, and the rate of recovery of fertility is considerably slower, there is no reason to believe that the long term usefulness of this area has, as yet, been irreparably impaired.

In test Area 3 (Figure 6.2) the bed load of the Rio Pedro bears witness to the rapid rate of soil loss in the area. There is much evidence in the fields of aggrevated soil loss but as in Areas 5 and 6 the land appears to recover very rapidly when rested. Bamboo has been planted to prevent headward erosion of a number of small gullies. The bamboo has spread from these and colonised areas of abandoned cultivated land. Parts of the slopes on the northern side of the Rio Pedro have been terraced and, unlike a number of areas of terracing seen while carrying out the traverses, these terraces are well maintained. In general the detail study of the seven areas above support the conclusions arrived at during the traversing.

Firstly there are marked differences in the importance of soil erosion in terms of the long-term use of the land between the limestone areas and those of igneous or sedimentary deposits. Any soil loss in the limestone areas is likely to cause permanent harm to the potential of the land for future use. In the other areas there are considerable short-term problems caused by the soil loss, the increased difficulties involved in cultivating eroded land, the rapid loss of fertility and the problems caused by the heavy sediment load of the drainage system and the increased rate of runoff. In the medium term these areas, due to the great depth of the mantle, recover their fertility after being rested for a few years. Hewitt (1979) has even suggested that the high rate of soil loss is necessary to maintain the fertility of the soil.

Secondly there has been little or no systematic work aimed at controlling erosion - even within the large commercial estates. Within the estates bank erosion is very common, as is gullying originating in the steep river banks. There has been no attempt made to restrict cultivation of the banks themselves and this has aggrevated the problem. In the hilly marginal lands there has been little attempt to control soil loss either by controlling overland flow or by increasing infiltration. Even such simple measures as cultivation along the contour, rather than up and down the slope, have been largely ignored.

CHAPTER 7

DATA HANDLING

Composite overlays at a scale of 1:12,500 were made on translucent drawing material of soil, slope and land use. Soil/slope boundaries were drawn in orange, and land use boundaries were drawn in either red or black to contrast with those of soil/slope. Up until this stage the boundaries of the study area had only been approximately marked on the maps; plotting of land use, erosion, soil and slope having been carried out well beyond the approximate boundaries to ensure complete coverage of the study area. Before any measurements could be carried out, however, it became necessary to delineate both the parish boundaries which delimited the area to the north, east and west; and the line running from Juan de Bolas to Above Rocks, which marked the southern limit of the study area. This southern limit roughly corresponds to the most northly ridge of the southern limestone upland (See Map 3, enclosure). Areal measurements were carried out on the Hewlett-Packard 9874A Digitizer used in conjunction with the 9825A Desktop Computer (Figure 7.1). The advantages of using this system over other methods of areal measurement lie chiefly in the high accuracy (and repeatability) of the individual measurements, the ease and speed of measurement, and the capability of using the computer to apply scale changes and to aggregate the areas with the same characteristics. A small amount of software is supplied with the digitizer including a program to measure areas. Unfortunately the program, as supplied, does not give good repeatability with the results, as it does not automatically close back to the point initially digitized. A single additional line ensures that the area to be measured is always closed and gives the repeatability needed.

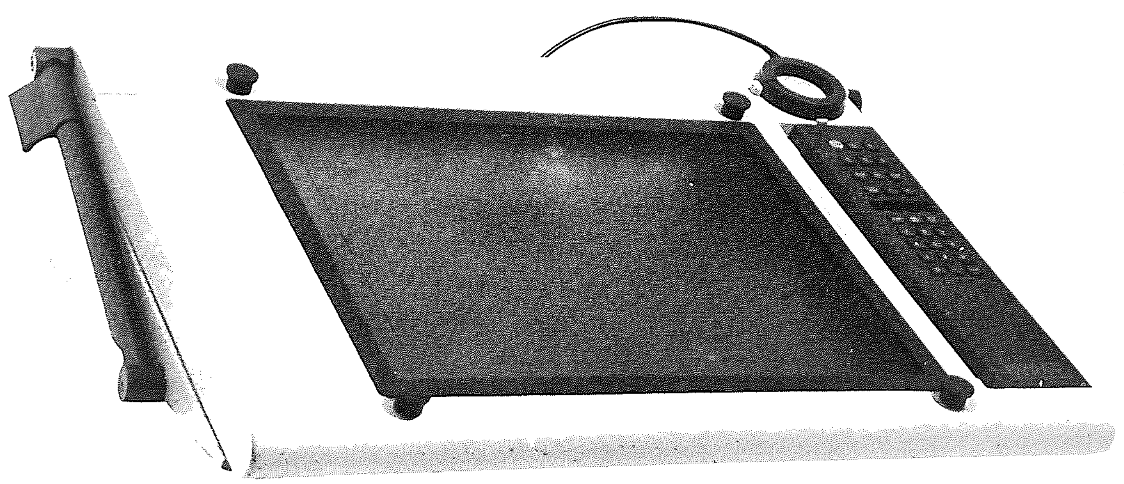


Figure 7.1 The Hewlett-Packard 9874A Digitizer

This fact has been brought to the attention of the manufacturers and all future purchasers of the equipment will be supplied with corrected software. After correcting the program, areas on the map of up to 24 square inches were measured with a repeatability of $\pm$0.002 square inches. All measurements were made in square inches at map scale, since if a scale factor was applied to bring the measured areas to hectares it was found that the display on the digitizer would overflow if areas covering more than two or three square inches, at map scale, were measured. Output from the computer was kept in square inches and was printed on a paper tally-roll. It was not felt important to convert the output to hectares since it was anticipated that the percentages of each combination of soil, slope and land use eroded would yield more information than the absolute amounts involved. There were a number of disadvantages in using this system however. The storage capacity of the computer is only 21K which, after using about 5K for the program to control the digitizer and output the results, left only about 16K for data storage. When storing normal numbers the computer allocates 8 bytes per number or, on reduced storage, 4 bytes. Within the study area there are 29 soil types (although this is increased to 44 if mixed associations are included), six slope classes (although this is increased to 25 if the mixed slope classes are included) and 18 land use classes (increased to 42 if mixed land use classes are included). For storage purposes this would involve setting up a three dimensional array of at least 29x6x18 (or 3132) locations, or, if mixed classes were included, 44x25x42 (or 46,200) locations. Since the mixed classes cannot be eliminated without falsifying the results, the higher number would seem to be inescapable. This would imply a storage capacity of 184,800 bytes, or about 180K; far beyond the storage capacity of the available computer. The amount of storage needed could be halved by using integer storage which requires only two bytes per number. Integer storage has the disadvantage that the maximum size of a number that could be stored is about 96 and that it introduced an error of ±0.001 square inches at digitiser scale. Both of these constraints were considered to be acceptable, but that still left a requirement for about 90K of storage. As only about 16K was available within the computer it was decided to reduce to a minimum all redundant storage by eliminating the combinations of soil and slope which do not exist and to develop a two dimensional array of soil/slope against land use. After determining which combinations of soil and slope actually occur, a conversion table was drawn up to convert each combination of soil and slope to a number between 1 and 181. The land use codes also had to be converted into numeric codes so a further conversion table was drawn up for this purpose. By this method it was possible to store all the measured data on the computer, and obtain printouts for each quarter sheet. Soil/slope numbers 182 to 187 were later allocated to combinations which had not been anticipated at the time of setting up the array.

The need to convert the codes used on the maps into the codes used for storage, necessitated two people carrying out the area measurements, one person working on the digitizer and calling out the area codes, while the other person converted the codes and keyed in the storage codes on the computer. If it had been possible to use the original codes the computer could have been programmed to read the codes from the keyboard of the digitizer, thus allowing one person to carry out both operations comfortably. The 9825A computer is due to be up-rated to 64K storage, thus allowing any future work to be carried out more easily and with only one person.

The same procedure was carried out separately to determine the total of eroded land for each soil/slope/land use combination within the study area. The codes used for work on the computer are given in Appendix H.

The computer outputs for each quarter sheet were then collated using one of Civil Engineering Department's Commodore Pet computers with 32K storage. This was carried out in two stages; collating soil/slope numbers from 1 to 100 and then from 101 to 187. This process was dictated by the limitation on the size of array that could be set up within the computer. This computer was also programmed to total the areas, and to convert into hectares both the total for the study area and the totals for the individual soil/slope/land use combinations. After collation the totals were printed out for each combination. It was found at this stage that of the 46,200 possible combinations of soil, slope and land use, 915 combinations actually occurred within the study area, and of these, 273 show some signs of soil erosion. The soil erosion figures were then combined with the land use, soil and slope figures to determine what percentage of each soil/slope/land use combination had been eroded.

From these figures it was possible to determine those combinations of soil, slope and land use which gave the most erosion, and thos which gave little or no erosion. In order to try to determine which of the three factors - soil, slope or land use - most affected the rate of erosion, it was necessary to carry out further data handling. This was carried out on the University of Aston's Hewlett-Packard HP2000 computer using the University of Chicago 'Statistics Package for the Social Sciences' (SPSS). It was necessary to use this package because there was insufficient time to develop special programs, and most of the other available packages were designed for use with parametric data. As a first stage a series of cross tabulations were obtained of slope, soil type and land use against percentage soil erosion. These were designed to give some indication of distribution of the different factors and their relationship to the percentage erosion. In order to carry out this exercise it was necessary to group the erosion data into discrete classes. It was decided to group them as in table 7.1

TABLE 7.1 Percentage erosion classes

Class 0	No erosion
Class 1	0 to 1% erosion
Class 2	1 to 3% erosion
Class 3	3 to 5% erosion
Class 4	5 to 10% erosion
Class 5	10 to 20% erosion
Class 6	20 to 50% erosion
Class 7	50 to 100% erosion

This approach proved useful with respect to slope data (see Tables 8.5a and 8.5b) but less so with the other variables since it only served to emphasise how interrelated are soil type and land use.

A more fruitful approach was to look at the relationships between those land uses and soil types upon which high percentages of erosion have occurred. Some filtering of the data was carried out since it was felt that if a combination of soil, slope and land use occupied less than five hectares, it would be unlikely to provide reliable results. Filtering was also carried out at one hectare and ten hectare combination sizes to determine if this caused much change in the results. Filtering at one hectare allowed in too much data to be easily handled, while filtering at 10 hectares would have removed all but three of the combinations having more than 20% eroded land.

Probably the most revealing treatment of the data was when the percentage of eroded land for each soil type and land use was calculated. This was coupled with the figures for the percentage of the study area covered by each of the soil types and land uses, and the percentage of total eroded land provided by each land use and soil type. Means and standard deviations were then calculated for percentage of eroded land, for both the land uses and the soil types. The results from these treatments of the data are discussed in the next chapter.

CHAPTER 8

ANALYSIS OF RESULTS

8.1 Introduction

The analysis of the results of this research programme fall fairly conveniently into two. Firstly there are the practical results indicating which combinations of soil, slope and land use give the least and the most erosion. These results could serve as a basis for reinforcing the 'good' practices and for discouraging or eliminating the 'bad' practices. The past history of conservation work in Jamaica, however, leaves little room for hope that any such recommendations (see Chapter 9) will be acted upon.

Secondly there are the theoretical results of this programme which serve as a basis for studying the relative importance of the three factors, soil, slope and land use in determining the amount of soil erosion that has occurred or will occur. As has been mentioned in Chapter 2 (Soil Erosion) there is a considerable body of test plot data which seems to indicate that land cover is the factor having the greatest influence on the rate of erosion. If the data from this project were to confirm the test plot data quoted in Chapter 2, it would indicate that researchers such as Lal are working in the right direction, whereas those seeking to impose an engineering solution, through terracing etc., are following an approach that, despite the very high cost of implementation, is unlikely to be successful in the long term in Jamaican conditions.

8.2 Determination of land use recommendations

To carry out the initial part of the analysis it was first necessary to separate out the combinations of soil slope and land use upon which no erosion had been observed, from those upon which erosion had been observed. Of the 916 combinations which do occur 270 are associated with some degree of soil erosion. It was decided that in the first instance a certain amount of sieving was necessary to remove those combinations within the study area that occupy less than one hectare. A second sieving was then carried out to remove all combinations occupying less than five hectares, as it was found that the volume of data was still too large to be readily used, and the significance of the results obtained from such small areas would be suspect. On the basis of these results a list was then drawn up of recommended land usages for each combination of slope and soil. The combinations of soil, slope and land use exhibiting soil erosion were then sieved in a similar manner to remove those combinations that occupy too small an area to be statistically significant. Combinations exhibiting up to three percent erosion were then added to the list of recommended practices, it being felt that their impact on overall erosion was relatively small and, in a number of cases, their economic significance was quite large. The combined list is given in Appendix J.

The combinations exhibiting more than three percent erosion were then examined with a view to drawing up a list of practices that should be actively discouraged. It was felt that any land use causing more than 20% erosion on a particular soil/slope combination should be actively discouraged and a list was drawn up accordingly. A further list was drawn up of those combinations falling between 10 to 20% where it was felt that the practices should be discouraged though with less urgency than for those practices exhibiting higher percentages of erosion.

Table 8.1 gives the soil/slope/land use combinations which exhibit more than 20% erosion of the land surface. Table 8.2 gives a similar list for land having between 10 and 20% of its

Table 8.1 Combinations of soil type, slope and land use having more than 20% of the land surface eroded (areas of more than 5 hectares only)

Soil Type	Slope	Land Use	Area (hectares)
35	E	2a/f	15.5
63	B	1a/e	6.0
63	B	2f/7	20.4
75	D	7	7.9
75	C/D	3/6	17.0
75	D/E	1a/e	7.1
75/77	E/D	8	5.8
77	E	3/7	8.5
77	E	3a/6	5.7

Table 8.2 Combinations of soil type, slope and land use having between 10 and 20% of the land surface eroded (areas of more than 5 hectares only)

Soil type	Slope	Land use	Area (hectares)
6	B	1a	15.5
13	B	1a	123.1
33	B/C	1a	8.5
34	E	2a	7.2
36	C	3/7	9.1
36	D	3/7	28.8
61	D	3/6	11.9
63	C	1a/e	15.9
74	B/C	2f/6	16.9
75	D	1a/7	14.4
75	E	7	8.1
75	C/D	2f/7	13.5
75	C/D	3b	7.2
77	E	1a	10.2
77/78	E/F/D	3b	7.9
77/95	E/F/D	1a/7	6.2
78	E	3/6	7.1

surface eroded. The significant fact about both lists, singly or in combination, is the narrow range of soil types and land uses represented. Soil types 63, 75 and 77 occur on both lists as do land uses 1a, 1a/e, 2f/7, 3(a)/6 and 7. It is however extremely difficult to draw any easy conclusions from these occurrences. A more detailed analysis of the data is included in Chapter 8.3. In view of a number of important land uses being associated with large amounts of soil erosion it was felt that a more detailed look should be taken at the economically more important of them.

Probably the most important of all the land uses on Tables 8.1 and 8.2 is 1a (plantation sugar cane). Table 8.4 shows that 4.10% of the land in sugar plantation is eroded, and this accounts (see Table 8.7) for 22.22% of all the eroded land within the study area. Most of this erosion has occurred on gently sloping land and on good soils, it is important, therefore, to understand what is causing this erosion on such an important crop. An examination of the aerial photographs reveals that most of the erosion is caused by the sugar cane being planted right up to the banks of rivers and streams flowing through the plantations. This has resulted both in bank erosion and in the development of gullies perpendicular to the bank. Figure 8.1 was taken of a stretch of river bank along the Rio Doro within the New Hall estate. It clearly shows how the cane has been planted right up to the river bank, and the unstable nature of the bank. Figure 8.2, also on the New Hall estate, shows how cane has been planted across a drainage ditch instead of following the recommended practice of leaving the ditch grassed. Figure 8.3, also on the New Hall estate, shows the ground between two rows of cane planted in the direction of slope. The soil has been compacted, and this, coupled with the direction of planting, is encouraging overland flow. These

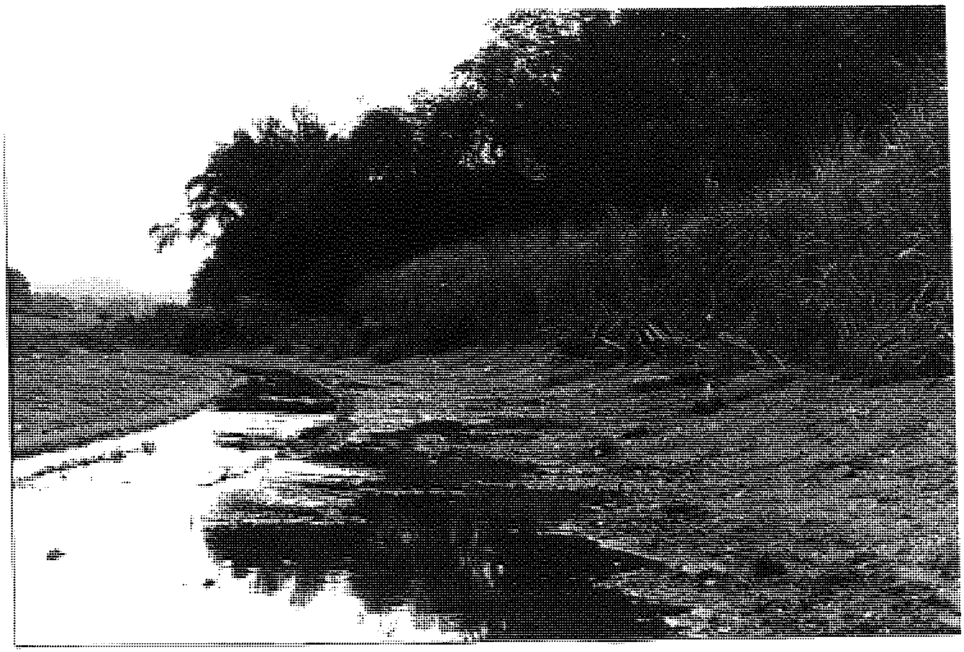


Figure 8.1 Cultivation of Sugar Cane along the Rio Doro

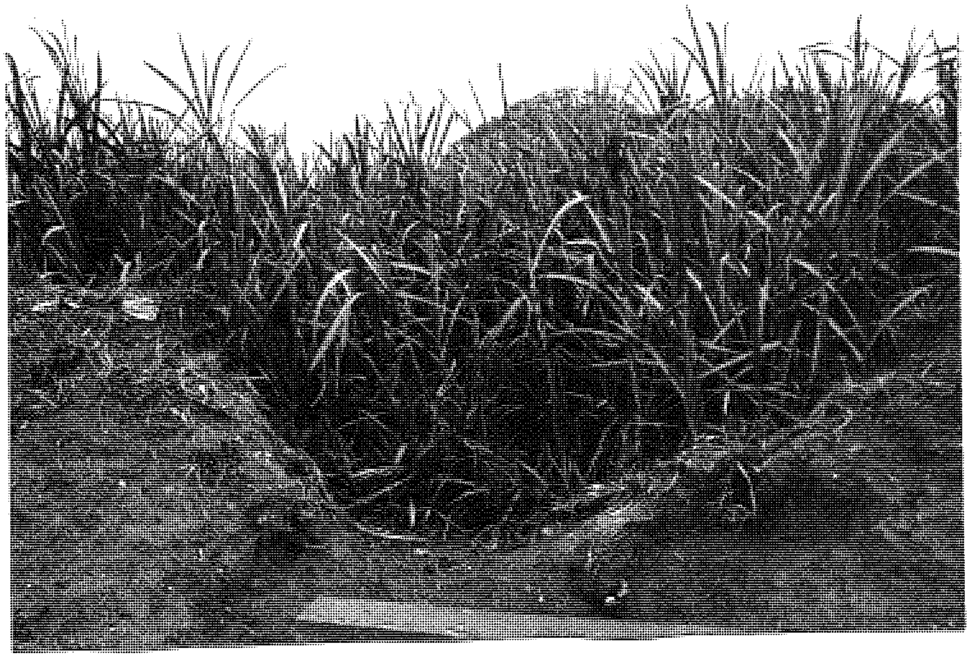


Figure 8.2 Cultivation of Cane across a Drainage Ditch, New Hall Estate

Figure 8.3 Cultivation of Cane Perpendicular to the Contour, Ground Showing Signs of Surface Compaction, New Hall Estate.

examples are by no means atypical, similar photographs could have been taken on any of the large estates. What these photographs illustrate is that it is not necessarily the crop that is causing the erosion, but rather, at least in the case of plantation sugar, the methods of cultivation and management employed. Simple policies such as not planting within ten metres of any water course, leaving all drainage ditches grassed and planting along the contour should serve to eliminate much of the problem. On these grounds it is felt that, although plantation sugar is included within both Table 8.1 and Table 8.2, it would be unrealistic to make a recommendation that it should be discouraged. There are other reasons which could be advanced for switching the land to other crops but they do not fall within the province of this research programme.

Also very important are the various grassland classes listed in Table 8.1 and 8.2. In section 8.3 it will be seen that 3, 3a and 3b have been grouped together for the purposes of analysis, as have 3/6, 3a/6 and 3b/6. It was found from the point of view of soil erosion that there was little or no difference between the various grassland classes. The implication of this is that any differences in the quality of the ground cover are outweighed by the similarities in the management of the grazing. This appears to be borne out by a detailed study of just where the soil erosion occurs within the grassland areas. In most cases the erosion is restricted to the lines of the watercourses, the areas around drinking holes or troughs, and the cattle trails leading to milking sheds etc. The most serious areas are those associated with the watering of the cattle, especially where there is access to a stream or river. In most cases this has resulted in badly eroded banks and the development of minor gully features. There are areas where overgrazing seems to have resulted in erosion: such an area is shown in Figure 8.4. These areas seem to be restricted to the smaller holdings, but the other manifestations of bad management are not restricted to any group of holding size. As with plantation sugar it is not felt that a recommendation can be made to restrict the use of land for grazing, but it is felt that much more attention must be paid to the proper management of grazing if long-term erosion problems are to be avoided. Sufficient literature is already available for the apparent ignorance of proper grazing practice to be quite inexcusable, especially on the larger commercial estates.

In view of the high level of erosion on plantation sugar (1a), the relatively low level of erosion on small-holder sugar (2a) is perhaps surprising. Erosion, at 1.26% of the land in small-holder sugar, is below the average value for the whole study area, 1.54%. It is also significantly lower than the value for plantation sugar, 4.10%. Small-holder sugar may be observed on very steep slopes on poor soils, and the quality of the crop often seems very poor, but these areas rarely appear to initiate a serious erosion problem. Sheet erosion on a fairly minor scale may be observed on the ground, but is rarely detectable on aerial photographs. Gullying and rilling are rarely if ever observed either on the ground or on the aerial photographs. The degraded appearance of the crop seems to owe more to the thinness of the soils than to erosion problems. A number of factors may explain this absence of a serious problem. The small size of the field involved, surrounded as they usually are by natural cover, does not allow large volumes of water to accumulate in overland flow, thus limiting transport. The absence of clean tillage on these upland fields must also serve to help prevent erosion. Nowhere on the small-holder

Figure 8.4 Pasture in Poor Condition Showing Signs of Over Grazing

sugar could a photograph, as in Figure 8.3, have been taken of completely clean tillage. Figures 8.5 and 8.6 are fairly typical examples of small-holder sugar on the limestone derived soils.

Sugar cane grown in mixed stand with coconuts (1a/e) shows a similar degree of erosion to that of pure stand cane, rather than with pure stand coconuts which exhibit little or no erosion.

Food forest (7) (see Table 8.4) is characterised by an erosion rate of 2.36% which is rather higher than would be expected from such dense cover. Here the problem seems to be erosion originating along the lines of communications, footpaths and tracks, or in the occasional clearings. Mixed cultivation and food forest (2f/7) has a much lower erosion rate, more in line with that of mixed cultivation (2f). It is not at first sight clear why this should be the case since all three land use classes have the same sort of distribution in terms of soil type and slope, with, if anything, the distribution of 2f/7 having more in common with 7 than with 2f. The most likely explanation is that the reworking of the land surface in the areas of 2f/7 during cultivation has tended to obliterate the minor erosion features, or serves to make them less identifiable. Such minor erosion features would probably persist for longer under conditions of semi-natural cover obtaining in areas of pure food forest.

The relatively high level of erosion associated with non-agricultural land use (8) is largely due to problems relating to the bauxite plant at Ewarton, the higher runoff rate in urban areas, poor maintenance of roads and drainage systems and the grazing of roadside verges by goats and other domestic animals.

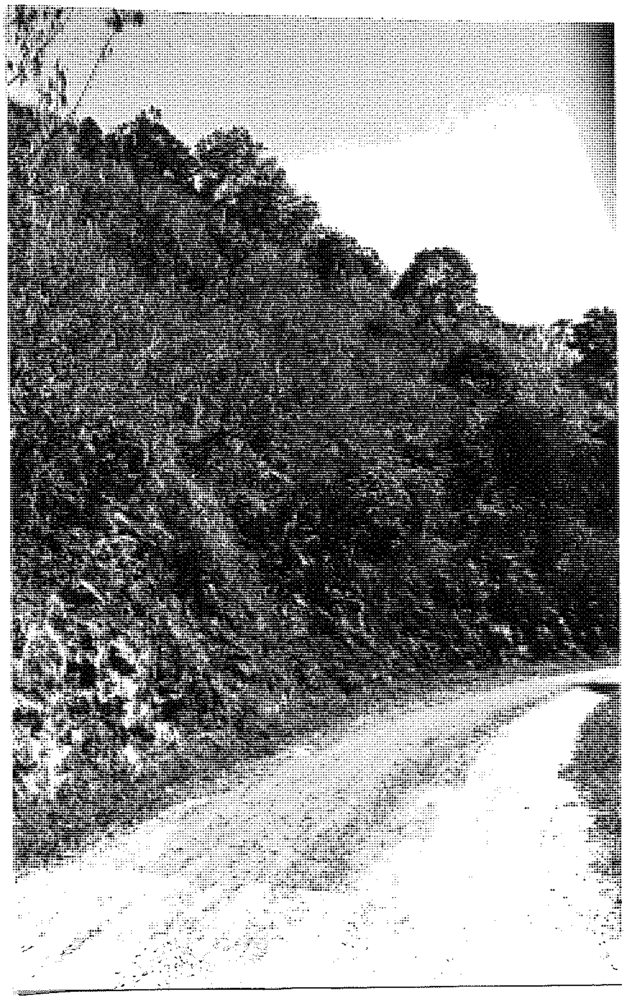


Figure 8.5 Small-holder Cane on Limestone

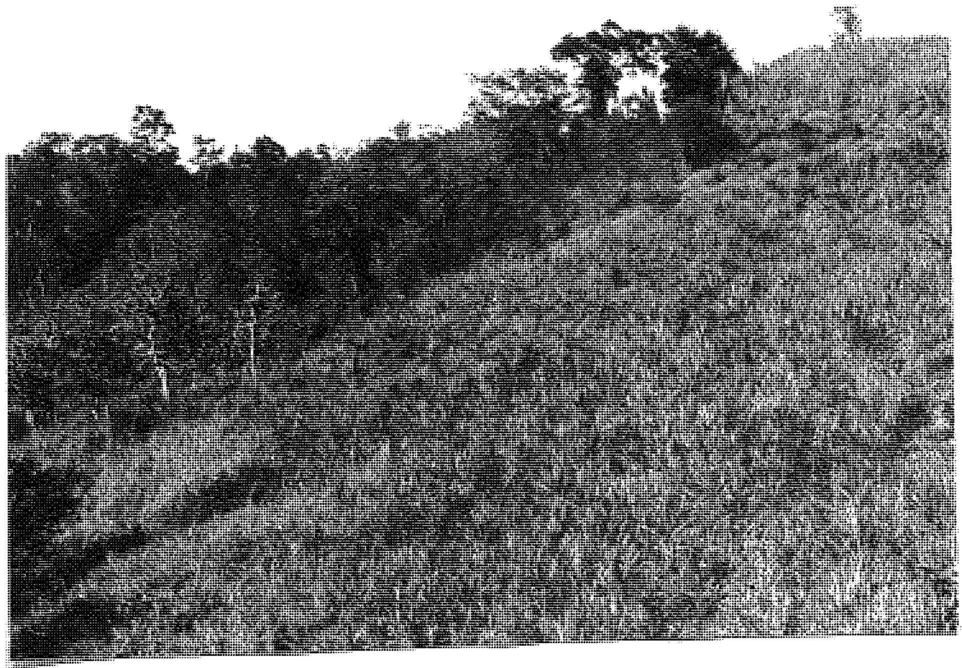


Figure 8.6 Small-holder Cane Showing Absence of Clean Tillage

Table 8.3 Erosion on the soils in Tables 8.1 and 8.2

Soil Type	% of soil eroded	% of erosion occuring on land uses in Tables 8.1 and 8.2
6	1.97	79.10
13	3.81	100.00
33	2.19	98.95
34	0.63	95.41
35	1.42	95.49
36	3.26	94.06
61	1.91	95.23
63	17.36	100.00
74	2.23	73.39
75	2.02	97.54
77	1.23	82.15
78	0.92	92.57
75/77	1.48	81.26
77/78	1.54	77.78
77/95	8.09	100.00

Table 8.4 Erosion on the land uses in Tables 8.1 and 8.2

Land Use	% of land use eroded	% of erosion occuring on soils in Tables 8.1 and 8.2
1a	4.10	79.25
1a/e	4.65	80.95
1a/7	3.27	81.68
2a	1.26	100.00
2a/f	0.99	84.48
2f/6	1.66	97.56
2f/7	0.98	47.57
3,3a,3b	1.70	86.81
3/6,3a/6,3b/6	2.00	95.32
3/7	1.94	96.80
7	2.36	86.04
8	3.28	100.00

8.3 Analysis of factors affecting the rate of erosion

Having drawn up a list of recommended land uses for each soil slope combination, the next stage was an attempt to use the data to find if it is possible to obtain information on the relative importance of soil type, slope and land use in determining the rate or amount of erosion. Test plot studies outlined in Chapter 2 indicate that the effects of soil type and slope are of about the same importance in determining the rate of erosion, but that land use is likely to be far more important than either in determining the rate of erosion.

As was mentioned in Chapter 7 the analysis of the data posed a number of problems due to it not being in parametric form (with the exception of the slope data). This precluded the use of principle component analysis or the use of correlation techniques, both of which rely on the data being in parametric form.

From the cross tabulations that were carried out on the three variables and the percentage erosion, it was clear that slope was not playing a large role in determining the rate of erosion. Table 8.5a and 8.5b both indicate little real increase in the severity of erosion with slope. This could, of course, be a function of a change in land use with slope, but the tables given in Appendix K, of land use cross tabulated with slope (with mixed slope classes aggregated up and down) indicate, if anything, that the land uses represented in Table 8.1 and 8.2 (i.e. those associated with large amounts of erosion) are more likely to occur on the steeper slopes than on the shallow slopes. If there is any increase in erosion it is in those erosion classes having up to 5% of the surface eroded. In these classes having more than 5% of the surface eroded there is, overall, no increase or even a slight decrease in the

Table 8.5a Cross Tabulation of Slope Classes by Percentage Erosion Classes (mixed slope classes aggregated up)

Slope	% Erosion Classes 0	1	2	3	4	5	6	7
A	63	5	7	3	3	0	2	0
% of row	75.90	6.02	8.43	3.61	3.61	0.00	2.41	0.00
B	128	7	9	6	6	3	3	1
% of row	78.53	4.29	5.52	3.68	3.68	1.84	1.84	0.61
C	117	10	9	5	6	6	1	3
% of row	74.52	6.37	5.73	3.18	3.82	3.82	0.64	1.91
D	141	20	18	3	9	7	7	0
% of row	68.78	9.76	8.78	1.46	4.39	3.41	3.41	0.00
E	103	12	15	6	6	4	7	0
% of row	67.32	7.84	9.80	3.92	3.92	2.61	4.58	0.00
F	92	25	21	5	2	3	2	0
% of row	61.33	16.67	14.00	3.33	1.33	2.99	1.33	0.00

Table 8.5b Cross Tabulation of Slope Classes by Percentage Erosion Classes (mixed slope classes aggregated down)

Slope	% Erosion Classes 0	1	2	3	4	5	6	7
A	68	5	7	3	3	0	2	0
% of row	77.27	5.68	7.95	3.41	3.41	0.00	2.27	0.00
B	126	7	9	7	7	5	3	1
% of row	76.36	4.24	5.45	4.24	4.24	3.03	1.82	0.61
C	161	2	3	0	4	2	2	3
% of row	90.96	1.13	1.69	0.00	2.26	1.13	1.13	1.69
D	174	35	34	7	9	7	9	0
% of row	63.27	12.73	12.36	2.55	3.27	2.55	3.27	0.00
E	86	12	14	5	3	5	5	0
% of row	66.15	9.23	10.77	3.85	2.31	3.85	3.85	0.00
F	29	8	3	3	1	0	0	0
% of row	65.91	18.18	6.82	6.82	2.27	0.00	0.00	0.00

number of occurrences. This would seem to agree with the findings in section 8.2 where it was found that plantation sugar, for example, suffered most of its erosion on the flat or gentley sloping areas, since most of the erosion was associated with bank erosion and minor gullying along the rivers. Small-holder sugar, which tends to be grown in the upland areas, is not so subject to such erosion. If there is little difference in the rate of erosion with slope, it follows that either soil type or land use (or a combination of both) is having the greatest influence in determining where erosion will occur and to what extent. Unfortunately whereas it can be shown that slope is having little effect on the amount of erosion, it is difficult to separate the effects of land use and soil to show which is having the greater effect. From the table in Appendix K it can be shown that land use is more or less independent of slope. A similar table of land use against soil type would indicate a fairly close association between soil type and land use. From Tables 8.3 and 8.4 it can be seen that there is a fairly close relationship between the soils and the land uses which appear on the list of those having more than 10% of the surface eroded. Table 8.6 which shows the percentage of the study area occupied by the listed soils, and also the percentage of the eroded land occuring on these soils, indicates some measure of agreement, with a few exceptions, between the area occupied by the soil and the amount of erosion present. Table 8.7 shows the same information for land use but here the discrepancies are more marked, especially in the case of 1a (plantation sugar) and 2f/7 (mixed cultivation and food forest). Appendix K contains full lists for all land uses and soil types. As mentioned in Chapter 7 it was decided to combine the totals for 3a (improved grassland) 3b (unimproved grassland) and 3 (where no distinction could be made) and also to combine 3a/6,

Table 8.6 The percentage of the study area and of total erosion for each of the soils listed in Tables 8.1 and 8.2

Soil Type	% of study area	% of total erosion
6	0.70	0.90
13	0.93	2.31
33	2.08	2.98
34	11.28	4.60
35	1.30	1.19
36	0.85	1.81
61	12.52	15.52
63	0.20	2.10
74	0.77	1.11
75	3.29	4.20
77	4.41	2.72
78	1.11	0.66
75/77	11.01	10.56
77/78	28.65	28.68
77/95	0.27	1.41

Table 8.7 The percentage of the study area and of total erosion for each of the land uses listed in Tables 8.1 and 8.2

Land Use	% of study area	% of total erosion
1a	8.68	22.22
1a/e	0.62	1.89
1a/7	0.39	0.83
2a	0.65	0.53
2a/f	2.54	1.64
2f/6	12.50	13.51
2f/7	32.35	20.63
3,3a,3b	2.71	3.00
3/6,3a/6,3b/6	13.76	17.90
3/7	2.22	2.81
7	1.28	1.96
8	0.19	0.41

3b/6 and 3/6 (the various types of grassland in combination with woodland) since the results for the components of the combined groups were so similar. The mean and standard deviation of the percentage erosion were calculated for all the soil types and for all land use types. The standard deviation for the soil types was found to be 2.92, while that for the land use types is 6.80. Since, however, the distribution of the percentage erosion figures does not conform to a normal distribution, it would be rash to make any direct comparisons between the two groups in terms of the variance within the group. The distribution is in both cases skewed towards zero, and whilst there are areas of deposition no attempt has been made to quantify them as areas of negative erosion.

While not too much should be read into the standard deviations they are, at least, an indication that there is a wider variation within the percentage erosion figures for the land uses than there is for those of the soil types. If there is a wider variation in the percentage erosion figures for the land uses this would then seem to support the results quoted in Chapter 2. The differences, quoted in Chapter 2, between the effects of different land uses in terms of soil loss were obtained from test plots, measuring the mass of soil removed. Using this type of data it is possible to make the kind of comparisons already quoted from Hudson (1977). With the type of data used in this study, however, where the area of eroded land is used as a measure of the amount of erosion occuring, rather than using the mass or volume of soil removed, it is not possible to accurately assess how much erosion is occuring through sheet wash if it is not having a sufficient effect to register as an image on the aerial photograph. The fact that no erosion was identified on certain soil types and on certain land uses does not imply that no erosion is occuring. Rather it implies that whatever erosion is occuring on those soil types and land uses it is occuring at too slow a rate to effect the image characteristics. Fournier (1967), Lal (1976) and Hudson (1977) all quote rates of erosion as low as 0.025 tons/hectare obtained from test plot data. Such rates would be hard enough to observe in the field much less on aerial photographs. This sort of rate amounts to little more than natural or geological erosion and as such is of no real interest to this project except as some sort of 'control'. It was unlikely, therefore, that the type of figures quoted for the comparison between maximum and minimum rates from Hudson (1977) in Chapter 2 would have been obtained in this study.

On the basis of this study it has been possible to say that slope seems to play the least role in determining the rate of erosion, and that land use appears to have a greater effect than soil type, but it has not been possible to say what the differences are. It is, however, enough to suggest that the approach to soil conservation advocated by workers such as Lal, based on the modification of cropping practices, and the encouragement of the cultivation of crops less likely to degrade the soil, is more likely to be successful within a tropical environment than the approach, developed by the United States Department of Agriculture Soil Conservation Service in more temporate regions, which involves attempts to reshape the land and thus change the slopes. This would seem to be both a very costly and ineffective method of controlling erosion, and less logical than the attempts to modify the soil itself, as advocated by some workers.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

The history of past studies of soil erosion in Jamaica outlined in Chapter 2 lead almost inescapably to the conclusion that whatever recommendations are made in this study they are unlikely to be taken up. Several emminent specialists have visited the island but their recommendations relative to soil conservation have generally been ignored. It is only to be expected, therefore, that any recommendations which derive from an academic study such as this will also suffer the same fate.

Edwards (1961) quotes small-holder farmers as knowing what soil erosion or 'wash' is, as realising that the topsoil ('fat' or 'gum') is being removed and that this will result in 'pooring' of the soil causing it to become 'tired' or 'worn out'. He continues however that "the farmers felt that a higher rate of erosion was tolerable, than that approved by the agricultural officers. They preferred to erode the soil at a rapid rate during cultivation and then to allow it to lie fallow under pioneer grass for a few years. They favoured this course of action, which combines a relatively low level of investment with an absence of returns from the land for a lengthy period, to one which requires a higher investment but gives continuous returns - as is involved in securing more effective control of the rate of erosion".

The situation is aggrevated by the land tenure system where many of the small farmers are either tenants or share croppers who see little personal advantage to be gained from investment in conservation measures.

It is obvious that any proposals for soil conservation measures which fail to take account of the attitudes of the farmers are doomed to failure. It is not entirely surprising, given the institutional constraints within which they act, that the 'peasant' farmers are reluctant to 'improve' their methods of cultivation in the light of all that is known about the long term effects of accelerated erosion. What is surprising, however, is the apparant lack of awareness of the problem on the part of the large plantation owners and managers. It could be argued that the problem is due to the owners being unwilling to invest in soil conservation while the threat of possible 'socialisation' hangs over the large estates. This, however, would carry conviction only if the photography from 1961, when no such threat existed, showed no signs of the present problem, especially those along the Rio Doro watercourse. Unfortunately the photography for 1961 shows that the problem existed then, although perhaps not as severe as it is at present. The problems of soil erosion on the large estates, mostly a problem occurring where sugar is being grown or where cattle are being grazed, is almost entirely due to bad management rather than to inherent defects in the land uses being practised. In the last chapter mention was made of the nature of the problem on the sugar lands and on the grazing lands near the main rivers. Some mention was also made of the simple changes in management practices needed to alleviate the worst of the problems. It seems, however, that a 'carrot and stick' approach is needed to combat the problem both on the small farms and on the large estates. The carrot should take the form of subsidies to encourage the farmers to put in minor engineering works such as earth bunds and proper drainage which will help to control runoff. It should also take the form of subsidies to encourage farmers to try new crops or crop combinations which will provide good ground cover. These subsidies should take the form of guarantees that the earning level of the farm will be maintained should it be necessary for the farmer to adopt crops or cropping practices that would reduce his or her income. No farmer, especially those on or near the subsistence level, can afford to adopt crops or practices that will or might reduce his income. The 'stick' should take the form of regulations (which should be rigorously enforced) governing the more harmful practices such as cultivation of stream banks. Obviously such practices as tilling up and down the slope rather than along the contour cannot be legislated against because of the difficulties involved in enforcement despite the practices being so harmful. Appendix L contains some details of the present legislation in force in parts of Nigeria. These could serve as a basic framework upon which to base similar legislation in Jamaica. Some legislation does exist to control erosion in Jamaica but through lack of enforcement it has fallen into disrepute. A fresh start is really needed since it is obvious in the field that farmers have scant regard for the existing body of legislation even if they are aware of its existence. What is also needed is that the functions of soil conservation officers and enforcement officers need to be separated. If the functions are combined there will be too much distrust of the conservation officer to allow him to develop the rapport with the farmer necessary to gain acceptance of new practices. There is also a great need to up grade the post of conservation officer to the same level as extension officer, with the same pay, to allow the service to recruit a higher standard of staff. It would also help, of course, if the extension officers showed a greater concern for the problems of soil conservation but at present their chief concern seems to be to maximise yields irrespective of the long term effects. Ideally the function of extension officer and conservation officer should be combined since conservation farming is the one guarantee of continued high yields but realistically it is probably not possible to do so in Jamaica with all the constraints that exist within the system.

9.2 General Recommendations

1) Small-holder Cultivation. The results of this research programme have indicated where currently the greatest problems are at present in terms of soil erosion risk. One interesting feature which stands out is the relatively low level of visible erosion in the area of the soils on Granodiorite and Andesite, soil types 50, 51 and 59, in spite of the high erosion risk for soil type 50 and the moderate risk for 51 and 59 listed in the Soil and Land Use Surveys (Vernon and Jones, 1958). Hewitt (1979) explained this in terms of the relatively low fertility of the top soil which, when removed by erosion, exposes a mineral rich subsoil which helps to promote rapid regrowth of vegetation. It was his opinion that a relatively high rate of soil erosion was tolerable, or even desirable, on these soils to maintain a reasonable level of fertility. It is the rapid recovery of the natural cover after the abandonment of a field which obscures the slumping and major rilling which occurs while the field is in cultivation. Despite the absence of an agricultural problem on these soils, there is a severe problem of instability along the lines of roads and tracks, and it is these that will normally register on an

aerial photograph. A secondary problem does, however, arise and that is the problem of an increased stream load. Silting is a constant problem in the Rio Cobre reservoir which serves the Rio Cobre Irrigation Scheme on the coastal plain south of the study area. The Wagwater which supplies much of Kingston's domestic water also contains the same soils within its watershed. During periods of heavy rain the filtration plant is unable to cope with the increased turbidity and has to be closed down, leaving much of Kingston without water at the time when it is most plentiful. Spanish Town which receives part of its water from the Rio Cobre does not have the same problem since the irrigation scheme reservoir acts as a silt trap. The reservoir needs to be constantly dredged to remain functional. This also is not an entirely wasted effort since much of the sediment removed is sand low in calcium which is suitable for the building trade. It is difficult to decide upon a suitable course of action in these circumstances where a number of interests are in potential or actual conflict. Despite the relative infertility of the top soil on these Granodiorite and Andesite derived soils it is felt that the present system should be discouraged. It is obvious that if the subsoil is rich in minerals then the top soil must also have once been rich in minerals and that these have been lost through leaching or by being taken up by the plants. By increasing the use of organic fertilisers, green mulch etc. the farmers could reduce leaching and replace the minerals lost during cultivation. There would also be an improvement in the structure of the soil, increasing water holding and reducing surface runoff.

Mixed cropping should be encouraged wherever possible on the slopes of less than 20^{o}, with food forest as the dominant land use on steeper slopes. It is, however, realised that some holdings consist entirely of land on slopes in excess of 20° and that it would be unrealistic in such circumstances to expect the land owners not to grow field crops. In these cases bunding and contour drains should be installed wherever possible to control runoff. It is unlikely that advocating the use of strips of uncultivated land between strips of cultivation would lead to any acceptance of this practice since the farmers tend to regard the uncultivated strips as a waste of land. Prohibitions on cultivation of stream banks and the edges of roads and tracks should be rigorously enforced since this undoubtedly causes many problems.

On the limestone derived soils cultivation is, in many areas, extremely difficult if not impossible, due to the nature of the terrain and the extreme thinness of the soil. It is, however, possible in the cockpit bottoms and also on some saddles where a sufficient depth of soil has developed. On the saddles it is essential that conservation farming is practised since once the soil has been lost there is little or no hope of recovery. There is also a problem of water deficiency due to excessive drainage. Increasing the organic content of the soil would have the double effect of increasing the water holding capacity and decreasing the erodibility of the soil. Tree crops should be grown in preference, but again it is understandable if the small-holders are reluctant to forego field crops. Normal methods of conservation farming such as cultivation along the contour and the control of runoff, should be followed. In the cockpit bottoms the problems are not so acute since the slopes are gentler, reducing runoff velocity and indeed in some areas leading to net deposition. Erosion does, however, remain a problem and every effort should be made to encourage the farmers to adopt simple inexpensive conservation strategies.

On the alluvial soils there is relatively little small-holder cultivation since most of the rich alluvial land is in either plantation crops or pasture. What cultivation there is seems to pose little threat of creating an erosion hazard. Multi-cropping is a general feature of present cultivation with bananas grown in combination with coconuts and vegetables a common feature. Such a pattern of cultivation seems likely to minimise whatever risk of erosion that did exist. These are, however, the most suitable of the available lands in small-holdings for the cultivation of those crops, such as yams, that normally require clean tillage. The use of mulches would still be advisable for the crops that require clean tillage since the mulch will protect the soil from direct impact of the rain and help to prevent crusting thus preserving the permiability of the soil. The mulch will also reduce moisture loss and as it rots add organic material to the soil. Mulching is still a far from common practice in Jamaica except in St. Elizabeth (see Figure 9.1) where grass is grown to provide a mulch for the cultivation of onions. In St. Elizabeth the use of mulches is necessary to restrict water loss, but it obviously has all the other advantages associated with the practice. It is perhaps significant that the small-holders of St. Elizabeth are the most affluent on the island.

The small-holdings on the conglomerate, shale and meta-morphosed rock derived soils show some large areas of erosion. Although as a whole this group of soils is not eroded more than the average. These eroded areas do seem to be fairly localised and probably relate to individual cases of poor land use rather than systematic bad usage over the whole area.

Figure 9.1 Onions Grown Under Mulch in St Élizabeth

Figure 9.2 Slumping of Road Cutting Below Small-holder Cultivation

The soils of this area although of only low to medium fertility do seem to recover fairly rapidly, probably for the same reason as those on the Granodiorite. Similar procedures should be followed on these soils as on the Granodiorite derived soils with respect to conservation farming. Special care should be taken to ensure that cultivation does not take place at the tops of road cuttings, as in Figure 9.2, and that runoff from road surfaces is properly controlled.

2) Plantation cultivation only occurs on any substantial scale on the alluvial soils, and to a lesser extent on the limestone soils where the larger, more accessible, cockpits allow plantation type cultivation to take place. It has been noted in the previous chapter that, areally, the greatest amount of erosion occurs on plantation sugar. While only occupying 8.68% of the study area it accounts for 22.22% of all the land interpreted as eroded. The next highest total of eroded land, 20.63%, is for mixed cultivation and food forest (2f/7) and this class accounts for 32.35% of total land use. Most of the erosion on the plantation land occurs on the alluvial soils, which are also those of the highest fertility. It follows that action to reduce the rate of erosion in these areas is of primary importance. Several of the bad practices current on the plantation lands were outlined in Chapter 8, and included cultivation up and down the slopes rather than on the contour, cultivation across drainage ditches instead of leaving them grassed, cultivation of stream and river banks and cultivation up to the edges of tracks and roads which become foci for runoff. Furrows are also run straight down to and over the stream banks which helps to destroy the banks. Certain of the valleys also contain natural river terraces (the Rio Doro and Rio Magno systems are examples) and it seems to have been

common practice to cultivate the slopes between the terraces. These all show signs of severe erosion, but it was noted while doing field work that some of the worst examples, such as the Glora Gully (part of the Magno system), had been taken out of cultivation and were now in grass or semi-natural vegetation. If these plantation areas are ever visited by Conservation Officers it would seem as if the managers or owners pay as scant regard to their advice as do the 'peasant' farmers. Here, even more than in the hilly marginal lands, is a clear case for legislation backed up by rigorous enforcement. The chief crop responsible for erosion is undoubtably sugar, the other plantation crops such as bananas, citrus and coconuts exhibit far less erosion (bananas in fact exhibit no erosion). Very little needs to be done in the way of conservation measures on the alluvial soil, except if sugar is being cultivated, and even in the case of sugar simple common sense measures as outlined in Chapter 8 are all that are really necessary.

On the limestone derived soils there is not a strong relationship between sugar or other plantation crops and soil erosion. There are, however, still some problem areas and again the chief culprit is sugar grown under bad management, or on soils which are too infertile to support a proper crop (soil types 77 and 78). Except in the bottoms of the cockpits, plantation cultivation that requires tillage should be avoided. Citrus and coconuts are probably the best crops for the gently sloping limestone soils. Wherever the soil is known to be of very limited depth, or where the slopes are more than 15^{o}, it is best to avoid even the limited amount of disturbance necessary to establish citrus or coconuts. Such land is best left in woodland, with desired species such as Blue Mahoe being introduced (with the minimum of clearance and disturbance) into the semi-natural cover.

3) Grazing largely takes place on the alluvial soils and on the limestone derived soils, but also to a lesser extent on the soils derived from the highly weathered conglomerates.

It is on the limestone that the worst cases of erosion exist (see Tables 8.1 and 8.2). Most of the grazing on the limestone derived soils takes place in the cockpit bottoms, and it seems that erosion is initiated by the trampling of the cattle as they are moved to and from the pastures and around water troughs. The cattle tracks become foci for runoff and scouring occurs. Runoff is higher on and around the tracks because of soil compaction resulting from the trampling. A similar problem occurs around the water troughs. It is difficult to overcome the problem of runoff concentration on the cattle tracks, since with the often very narrow entrances to the cock-pits it is impossible to vary the route taken by the cattle. The route is often over quite steep ground where soil depth would already be limited and runoff rates higher. It is possible that the use of road stone or gravel on the tracks might alleviate the problem. The provision of proper drainage would also restrict the amount of runoff that could concentrate on the tracks. Water troughs should be moved at regular intervals to prevent excessive trampling of small areas. Obviously care should also be exercised to ensure that overgrazing does not occur since that will only aggrevate the erosion problem.

On the alluvial soils the main problem seems to lie in that the cattle are allowed to trample the stream banks and follow the same tracks in and out of the pasture and to and from water.

This has the same effects as trampling on the limestone derived soils. The simplest solution to the erosion of the stream banks is to fence the banks and to construct access points for the cattle both for crossing and for watering. These should be constructed of large cobbles set in gravel which while giving a firm footing for the cattle will allow for efficient drainage. Regulation of the grazing will also prevent over-grazing and loss of fodder due to trampling.

The problems on the conglomerate derived soils result from trailing and stream bank trampling. If anything the problems are more severe here due to the steepness of the terrain. Cattle trails on hillsides are a common source of accelerated erosion. The solutions to the problems on these soils are very much as outlined above.

4) Food forest is found on a wide variety of soil types but is largely absent on those over limestone. On its own it rarely poses an erosion problem and it is only when it is in combination with other land uses that special precautions need to be taken. The kind of precautions necessary are those applying to the other land uses. The chief cause of erosion in areas of pure food forest are related to communication. The kind of precautions to be taken have already been dealt with in the section on small-holder cultivation (1).

5) Woodland of the natural or semi-natural variety occurs on the limestone derived soil. The erosion problems occur when the woodland has been cleared for cultivation to take place or to exploit the timber. In the areas currently in woodland there is little scope for agricultural development and any attempts to clear the woodland for that purpose should be resisted.

At best only one or two crops could be obtained before the soil is lost with little future hope for recovery - even in woodland. Most of the present erosion scars are quite old, many of the areas still free of vegetation were in the same condition on the 1961 photography. Since these areas recover from erosion at such a slow rate, compared with the other soils, it seems folly to open them up for short term agricultural activity. Clear felling should be avoided wherever possible and this will be a considerable constraint on developing the limestone soils for timber.

There is probably considerable scope for the development of timber on the steepest areas of the Granodiorite and Andesite derived soils, and also those on the conglomerate and shale derived soils, but there has as yet been little attempt at forestry development within St. Catherine. There have, however, for a number of years been successfully established plantations of Caribbean Pine in St. Anne and St. Thomas. The Blue Mahoe has considerable scope for development as a decorative timber.

9.3 Conclusions

When this project was initiated there were three main aims. These were:

1) to determine if medium scale aerial photography could be used to study erosion problems in a humid tropical environment.

2) to determine which land uses were most and least likely to cause soil erosion and to draw up land use recommendations on the basis of these findings.

3) to find which of the three variables, soil type, slope and land use, was most responsible for determining the rate of erosion.

The first aim was satisfied when it was found that despite the problems caused by ground cover, an accuracy rate of approximately 75% could be obtained when comparing interpretation of photography ten years old with the present situation on the ground. By making an allowance for changes since the time of photography it was found that an accuracy rate of around 90% could be obtained if recent photography were used. It was also found that high contrast prints were significantly better for the identification of erosion features. It was hoped when this project was initiated that some of the 1:10,000 photography that covers the south-east corner of the study area could have been used to compare it with the results obtained with the 1:25,000 photography used for the complete study. This, however, proved to be impossible due to insufficient time and had to be abandoned although it could well repay future research. It had also been hoped to evaluate some infra-red false colour photography taken by NASA in 1971 as part of a LANDSAT simulation exercise, but upon inspection the imagery proved to be almost completely useless apparently due to bad exposure and processing. There would be scope for further research in this area given imagery of sufficient quality and consistency.

The determination of which land uses were most and least likely to give rise to a soil erosion problem was carried out with a fair measure of success. The results from the aerial photograph study were supported by the field observations. Based on earlier studies in Jamaica and the recommendations of the local Soil Conservation Service, however, the results do seem a little strange. The erosion problems associated with the bad management of plantation sugar and pasture have generally been overlooked whereas, by comparison with this study, the problems associated with the cultivation of the hilly marginal areas have been overstated. In discussion with Hewitt, an experienced Jamaican agronomist, the results of this research have generally been corroborated. It seems all the stranger, therefore, that so little attention has been paid by the local Conservation Service to the problems associated with plantation sugar and pasture.

The lack of parametric data rendered the analysis a rather subjective study of the relative importance of soil type, slope and land use in determining the rate of erosion. From the data obtained it was possible to see that slope was having very little effect on the rate of erosion, and that the differences between slopes were less than would have been expected by comparison with test plot studies. As was mentioned in Chapter 8 there were great problems in separating the effects of soil type from those of land use, since land use is to a large extent a dependent variable. The task was made more difficult by the non-parametric nature of the data, but it is suspected that the relationship is such that even using parametric data (by obtaining an index of credibility for the soils and a cover value index for the land uses) it would still have been difficult to separate the effects. This is certainly one area where the controlled conditions of test plots have great advantages over this kind of study. It is felt that, although it was not possible to quantify the differences between soil type and land use in terms of their respective impacts on the rate of erosion, the evidence does point towards land use as being the more important factor and that this would tend to support the type of test plot data quoted in Chapter 2.

Even were it to prove that soil type were more important than land use in determining the rate of erosion the fact that both are more important than slope adds weight to the ideas of researchers, such as Lal, who feel that changes in crops and practices are likely to prove more cost effective in controlling soil erosion in the humid tropics than the kind of practices advocated by the United States Soil Conservation Service. It is not really practicable to aim at modification of the soils inherent properties, although mulching and adding organic material to the soil will help reduce its erodibility. It would seem from the data collected in this project that modification of the topography, by terracing, will not substantially reduce soil loss unless it is backed up by changes in crops and/or cropping practices.

If there were any hope that the results of this study might have some effect on land use policy in Jamaica it might be worthwhile extending the study to the whole island, if only to identify where the problem areas are. The socio-economic and political constraints are such, however, that it is highly unlikely that the report, based upon the research described in this thesis, will have any effect. It is therefore unlikely that there will be any follow up in the other parts of the island some of which, such as the Yallahs Valley, suffer far more from an erosion problem than does the study area. It is felt that there is a potential for the methodology described in this thesis to be developed for application in other countries with similar environments to Jamaica. However, more research on the problems of soil erosion identification would need to be carried out before this methodology could be applied to areas of tropical rain forests.

APPENDIX A

Test Plot Data on the Relationship Between Various Crop and Land Management Strategies and Soil Loss

Table A.1 Showing the extent to which the protection of the soil by vegetal cover outweighs the effect of slope (after Fournier, 1967)

Station	Crop	Gradient (%)	Erosion t/sqkm/annum
Seredou (Guinea)	Cinchona	25	2,448
Kindia (Guinea)	Citrus on bare soil	6	1,787
Adiopodoume (Ivory Coast)	Bare soil	7	11,770
Sefa (Senegal)	Groundnuts	2	1,728
Sefa (Senegal)	Groundnuts	1	1,494

Table A.2 The relative efficiency of surface treatments in preventing runoff (modified from Lawes 1966)

Soil Surface Treatment	Runoff (%)	Max. infiltration rate (mm/hr^{-1})
Bare soil undisturbed	69	12.7
Bare soil hoed at fortnightly intervals	51	22.9
Bare soil hoed after every storm	43	30.5
Mulched with dead grass	10	> 127
Mulched with groundnut shells	11	> 127
Mulched with sorghum stalks	2	> 127

Table A.3 Comparison of soil loss and runoff with monoculture (cassava) and mixed cropping of cassava and maize (after Aina et al 1976)

Slope (%)	Soil Loss (tonnes/ha/yr)		Runoff (%)	
	Monoculture	Mixed Cropping	Monoculture	Mixed Cropping
1	2.7	2.5	18	14
5	87.4	49.9	43	33
10	125.1	85.5	20	18
15	221.1	137.3	30	19

Table A.4 Effect of slope steepness on soil loss (tonnes/ha) under continuous maize with mulch compared with the loss from bare soil IITA, Ibadan, Nigeria. Rainfall = 105.4 mm (after Lal in Greenland and Lal 1976)

Slope%	Bare Plot	Maize-Maize (mulched)
1	0.80	0.00
5	4.27	0.01
10	4.27	0.09
15	29.80	0.02

APPENDIX B

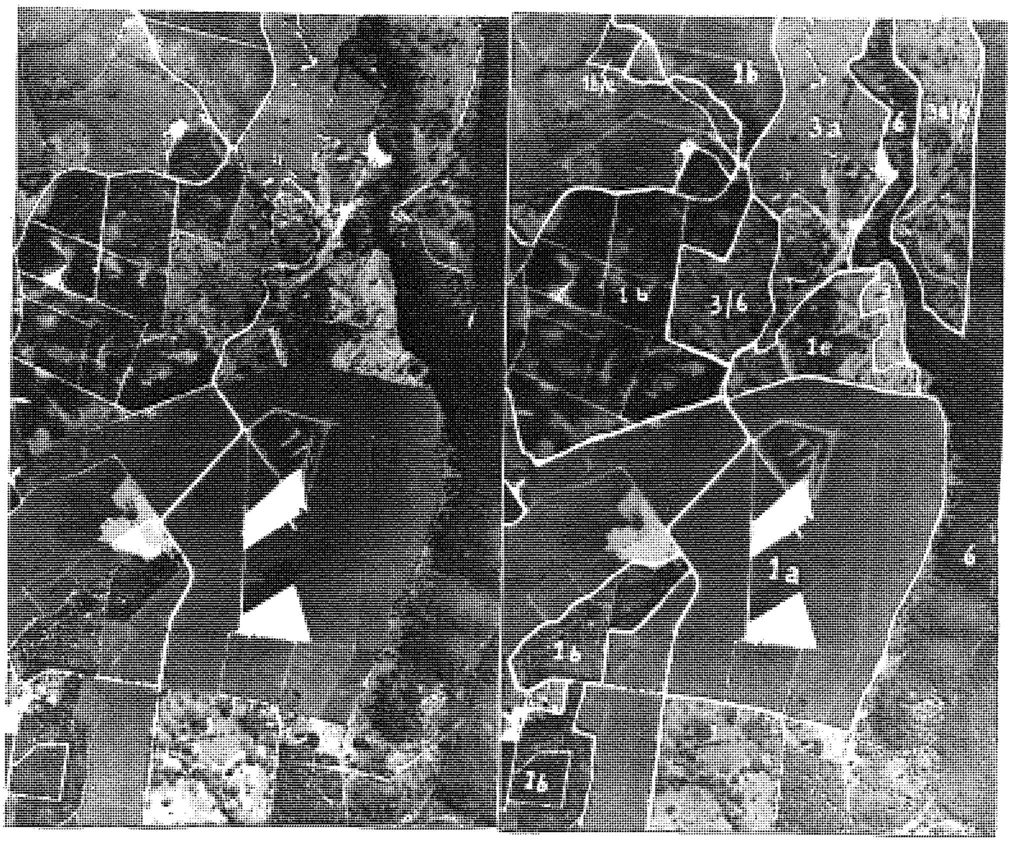
Agricultural Statistics for St Catherine (extracted from Jamaican Agricultural Census Unit, 1973)

Farm Size in Acres

	Landless	1	1–5	5–10	10–25	25–50	50–100	100–200	200–500	500
Number of Farms	1,109	4,927	10,096	2,694	1,161	193	64	43	31	31
Acreage of Farms	–	2,033	22,562	17,458	16,113	6,173	4,413	5,896	9,557	75,113
Pure Stand	–	512	7,248	4,903	3,517	1,086	1,121	1,240	1,049	23,828
Mixed Stand	–	667	8,730	5,555	3,992	862	276	288	264	51
Sugar Cane	–	38	1,327	1,263	1,084	368	418	745	471	19,546
Citrus	–	32	400	364	330	320	302	259	212	1,990
Bananas	–	95	933	541	304	79	104	20	47	497
Coconut	–	42	355	264	292	58	184	74	104	1,160
Food Forest	–	199	1,706	1,326	1,060	332	197	111	54	–
Grassland Improved	–	1	59	119	772	245	613	1,566	2,014	13,287
Grassland Unimproved	–	30	493	495	909	506	264	280	540	1,367
Woodland	–	2	178	532	1,174	646	542	822	2,248	18,013
Fallow	–	133	1,062	1,106	3,394	281	157	93	230	360
Dairy Cattle	215	668	1,210	774	598	307	416	1,036	958	3,416
Beef Cattle	160	369	805	448	561	91	117	226	138	5,093
Dual & Draft Cattle	6	23	898	187	126	21	24	48	32	608
Goats		7,001	7,402	3,429	1,799	516	145	249	60	240

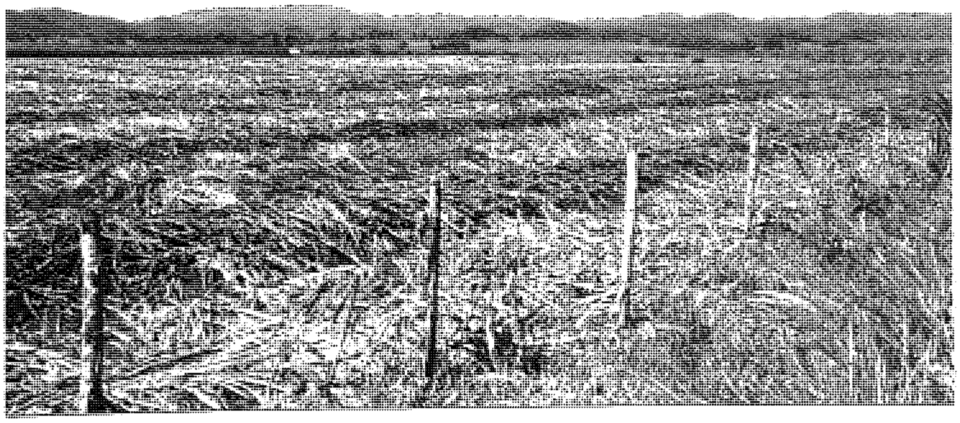
APPENDIX C

Stereo Pairs and Ground Photographs of the Major Land Use Types in the Study Area.



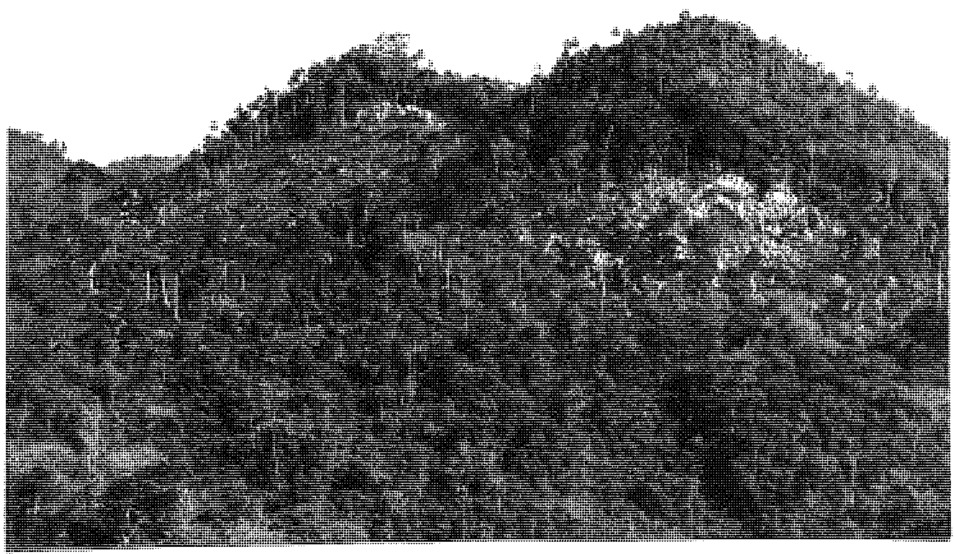
Stereo pair of the Wakefield area of St Catherine

Mature Plantation Sugar Cane (1a)

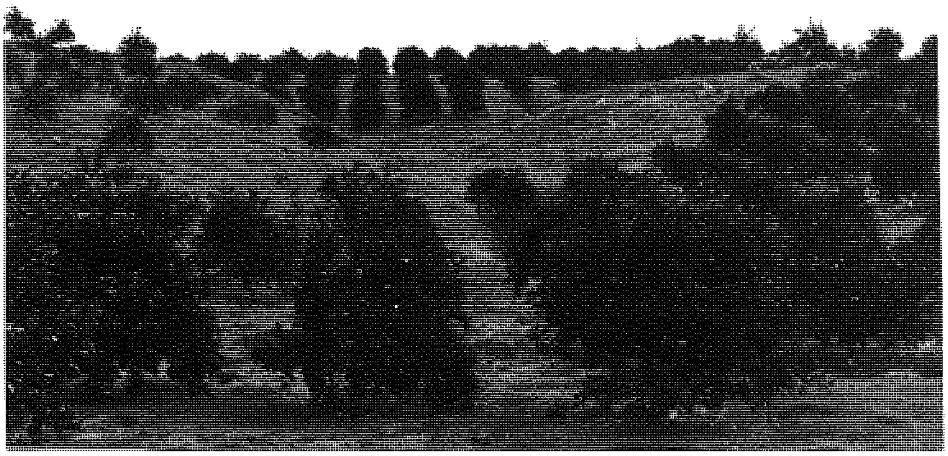


Burnt and Cut Plantation Sugar Cane(1a)

Ratooning Plantation Sugar Cane (1a)



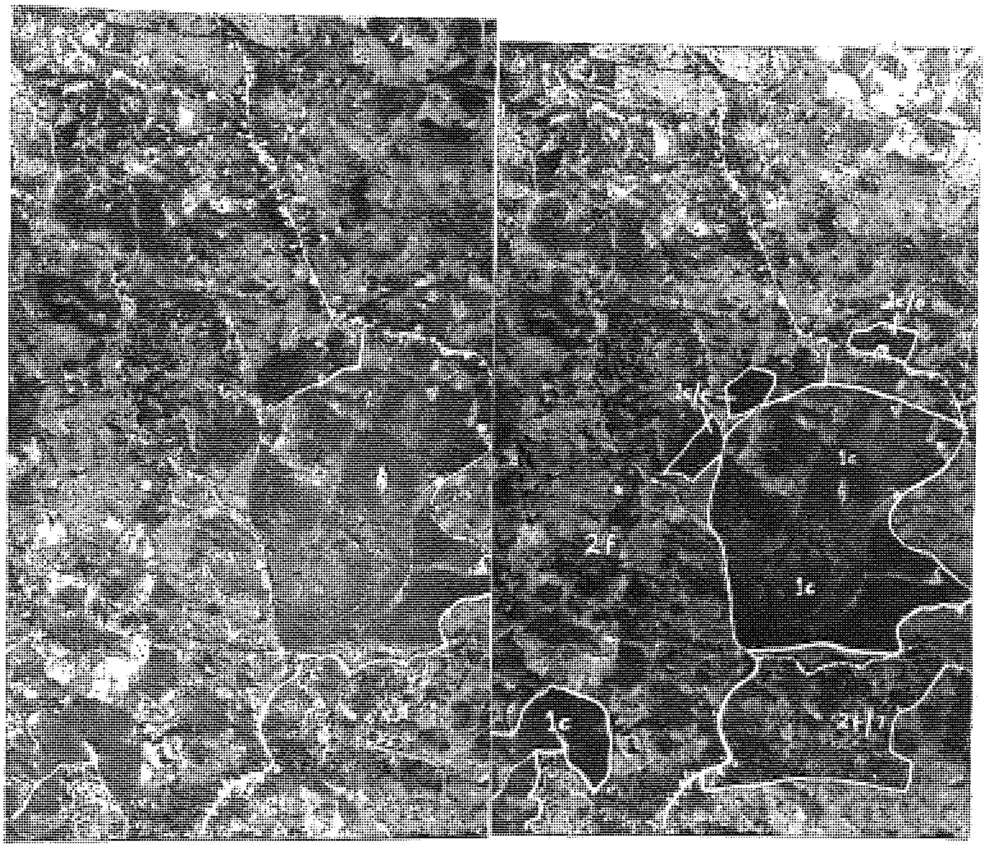
Woodland on limestone (6)



Plantation Citrus (1b)

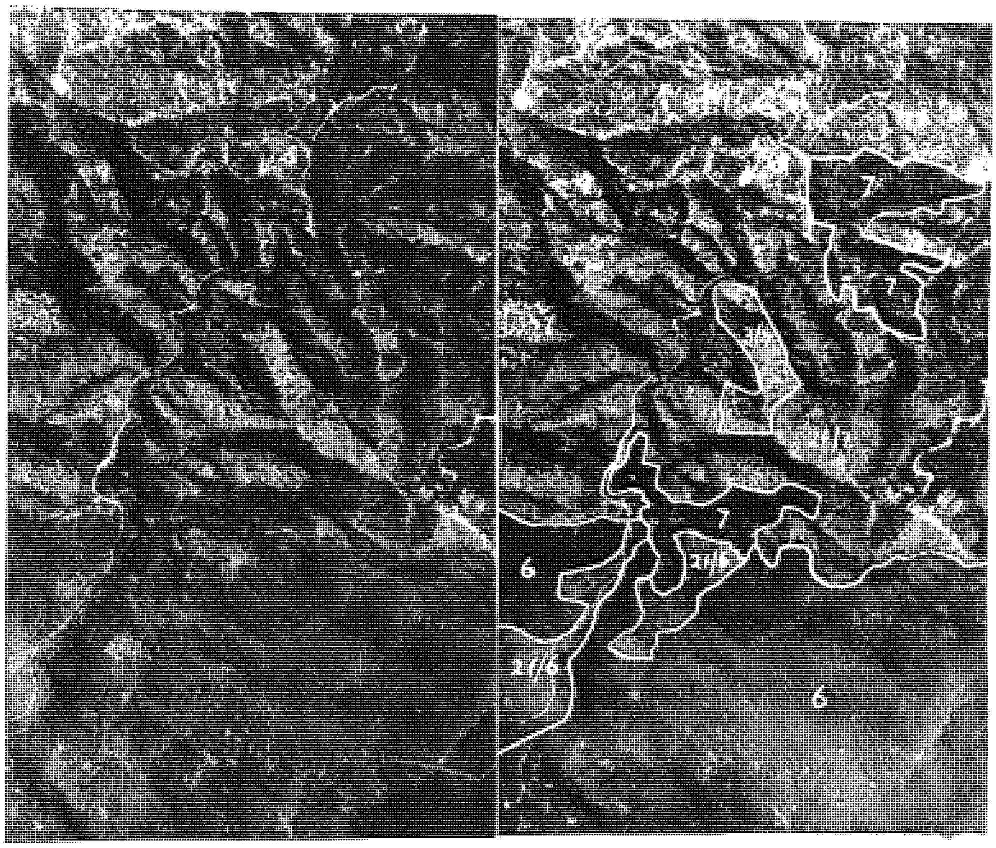
Plantation Coconuts, recent planting to replace those lost through lethal yellowing (1e)

Plantation Citrus and Coconuts (1b/e)



Stereo pair of the Guys Hill area of St Catherine

Mixed Cultivation and Food Forest (2f/7)

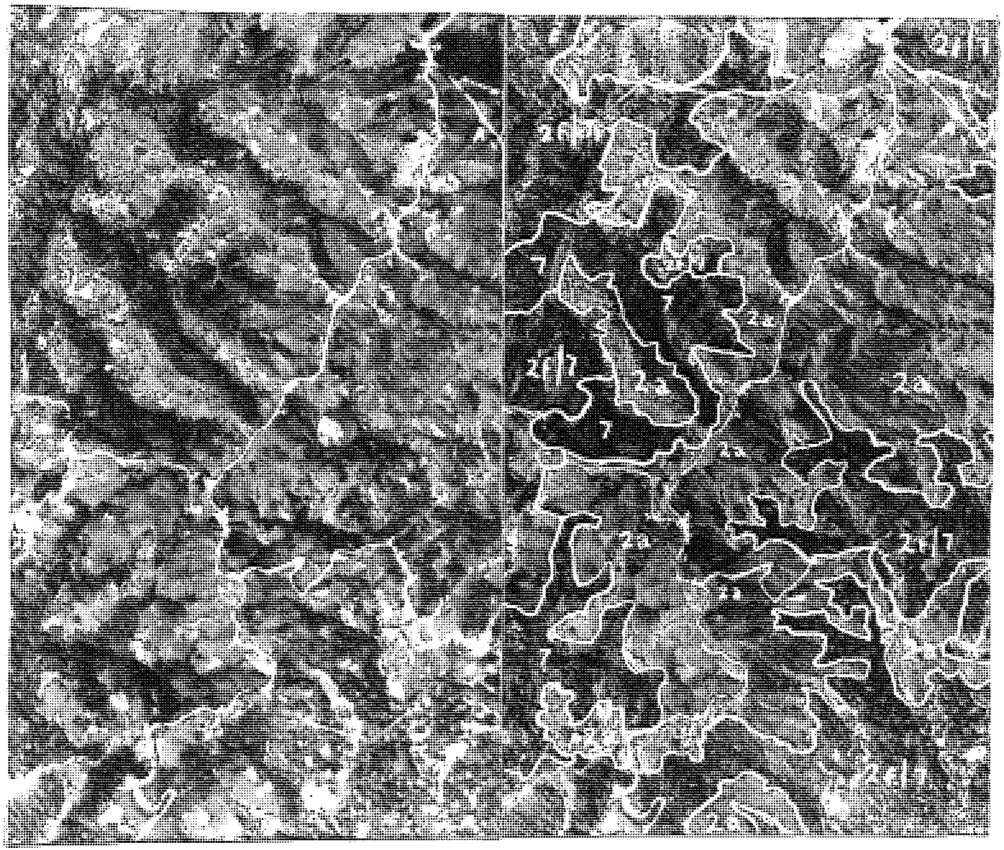


Stereo pair of the Mount Industry area of St Catherine

Improved Small-holder Cultivation and Food Forest (2f/7)

Food Forest (7)

Food Forest (7)



Stereo pair of the Juan de Bolas area of St Catherine

Small-holder Sugar Cane (2f)

Food Forest (7)

APPENDIX D

Data on the Stability of the Drawing Materials use during this Research Programme

Type of Map Used	Dimensions at Areal Measurement Stage
Printed Topographic Map	73.10 x 48.75 cm
Paper Dye-line of Topographic Map	73.40 x 48.70 cm
Dye-line on Plastic of Topographic Map	73.20 x 48.75 cm
Soil Maps (on paper)	73.20 x 48.85 cm
Tracing Paper copies of Soil Sheets	73.20 x 48.80 cm
Land Use Plot on Paper Base Maps	73.10 x 48.80 cm
Tracing Paper copies of Land Use Maps	72.90 x 48.85 cm

All the above dimensions are average values for the maps concerned and there is considerable variation within each type. Among the dye-lines on plastic bases, the most stable material, the length varies from the average by ±0.10 centimetres. Similar variations were found among the printed paper maps. The variations in size which are significant in terms of likely errors are those which cause a mismatch between the soil/slope data and the land use soil erosion data. Essentially this is the difference in size of the soils tracings and the land use tracing the average value of which are given above. It can be seen that there is little variation in width (0.5 mm) but that the lengths differ by about three millimetres. At first sight this may seem a significant error but by correct alignment of the sheets when overlaid the mismatch can be reduced to half this figure. It was also found that the plotting of boundaries on the original soil sheets could be up to five millimetres in error and, in one extreme case two centimetres in error (this error was obvious and so could be corrected). It was therefore felt that any inaccuracies in transfer of data due to material instability would be heavily out weighed by inaccuracies in the original plotting.

APPENDIX E

Soils of the Study Area (from Soil and Land Use Survey No. 1 Jamaica, Parish of St Catherine)

Soil No.	Soil Name	Parent Material	Dominant Slope Range	Moisture	Drainage	Erosion Hazard	Natural Fertility
6	Tulloch Sandy Loam	Mixed, sands and gravels	0 – 2°	Fair to low	Moderate to slow	Almost nil	Low to medium low. Acidic.
7	Tulloch Silty Clay Loam	Sandy and gravelly terrace	0 – 2°	Fair	Slow to very slow	Almost nil	Low to medium low. Acidic.
8	Knollis Clay	Old terrace material	0 – 2°	High	Very slow	Almost nil	Medium. Highly acid.
10	Berkshire Stony Sandy Loam	Recent alluvium	0 – 5°	Fair to low	Rapid	Moderate	Medium. About neutral.
11	Berkshire Sandy Loam	Sandy and gravelly recent alluvium	0 – 2°	Fair	Rapid to moderate	Moderate	Medium. About neutral.
12	Wallens Silty Clay Loam	Recent alluvium from Rio Magno	0 – 2°	High	Moderate	Almost nil	Low to medium low. Slightly acidic.
13	Rosehall Clay	Recent alluvium from interior basins	0 – 2°	High	Very slow	Almost nil	Low. Acidic.
14	Sterling Silt Loam	Recent alluvium from interior basins	2 – 5°	Fair	Very slow	Very little	Low to medium low. Acidic.
24	Agualta Sandy Loam	Recent alluvium	0 – 2°	Fair to low	Rapid	Slight except stream bank	High except for medium to low potash. Slightly alkaline.
32	Wirefence Clay Loam	Tuffs and Tuffaceous Shales	10 – 20°	Fair to high	Moderate	High to very high	Low. Very highly acidic.
33	Pennents Clay Loam	Interior basin deposits	5 – 10°	High to Fair	Very slow in subsoil	Moderate	Low to medium low. Highly acidic.

Soil No.	Soil Name	Parent Material	Dominant Slope Range	Moisture	Drainage	Erosion Hazard	Natural Fertility
34	Diamonds Clay Loam	Hornfels	more than 20^{o}	Fair to low	Extremely rapid to rapid	Very high	Low. Slightly alkaline.
35	Halifax Clay	Highly weathered acid shales and tuffaceous shales	$10 - 30^{o}$	High to fair	Moderate	High to very high	Low. Very highly acidic.
36	Donnington Gravelly Loam	Conglomerate and Ashes, mainly basic pyroclastic material	more than 20^{o}	Fair	Extremely rapid to rapid	High	Medium. Acidic.
46	Halls Delight Channery Clay Loam	Calcareous Shales	more than 20^{o}	Fair to poor	Extremely rapid	High	Medium. Neutral top-soil, alkaline sub-soil and parent material.
50	Flint River Sandy Loam	Granodiorite	more than 20^{o}	Very low to low	Extremely rapid	Very high	Medium to low. Neutral to slightly acidic.
51	Harkers Hall Loam	Colluvial from Granodiorite and its soils	$5 - 10^{o}$	High to fair	Rapid to moderate	Slight to moderate	Medium. Acidic.
59	Williamsfield Clay Loam	Granodiorite	$5 - 10^{o}$	Fair to High	Moderate	Slight to moderate	Low to medium. Acidic.
61	Linstead Clay Loam	Inland basin deposites	$5 - 10^{o}$	Fair	Very slow in subsoil	Moderate	Low to medium low. Highly acidic.
63	Palm Clay	Interior basin deposites	$5 - 10^{o}$	High to Fair	Very slow in subsoil	Moderate	Medium low. Highly acidic.

Soil No.	Soil Name	Parent Material	Dominant Slope Range	Moisture	Drainage	Erosion Hazard	Natural Fertility
66	Tydixon Loamy Sand	Interior basin deposites	$0 - 5^{o}$	Very poor	Very slow	Moderate to high	Extremely low. Very acidic.
74	Lucky Hill Clay Loam	Colluvium from hard white limestone and its soils	$0 - 5^{o}$	Fair to high	Very slow in subsoil	Very slight	Fairly high. Slightly to markedly acidic.
75	Union Hill Stony Clay	Hard limestone	$10 - 30^{o}$	High	Moderate	Slight to moderate	Medium. Neutral becoming alkaline below.
77	Bonny Gate Stony Loam	Hard White Limestone	more than 20^{o}	Very low	Extremely rapid	Very great if cultivated	Moderate.
78	St Ann Clay Loam	Hard White Limestone	None	Poor	Extremely rapid	Moderate to high	Low. Acidic.
79	Bundo Clay	Colluvium from limestones and their soils	$0 - 5^{o}$	High	Very slow	Very slight	Moderate. Very low phosphate. Highly acidic.
94	Carron Hall Clay	Soft rubbly limestone	$10 - 20^{o}$	Very high	Moderate often slow in subsoil	Moderate to slight.	High to very high. Increasingly alkaline with depth.
95	Waitabit Clay	Yellow Limestone Shales	$10 - 20^{o}$	High to fair	Moderate to good	High to very high	Medium to low. Highly acidic.
96	Wildcane Sandy Loam	Sandstone beds in Yellow Limestone Shales	$10 - 30^{o}$	Poor to fair	Very Rapid	Very High	Very low. Acidic.
98	Deepdene Clay	Yellow Limestone Shales	$2 - 10^{o}$	High	Very slow	Moderate	Medium to low. Highly acidic.

Soil No.	Soil Name	Parent Material	Dominant Slope Range	Moisture	Drainage	Erosion Hazard	Natural Fertility
106	Lluidas Gravelly Clay Loam	Gravally recent alluvium	$0 - 2^{o}$	Fair to low	Very rapid	Almost nil	High to medium. Slightly alkaline.

APPENDIX F

Land Capability Classification(from Soil Survey and Land Use Survey No. 1 Jamaica, Parish of St Catherine)

Land Capability Class	Most Intensive Suitable Use
I A and B slopes of good soils	Suitable for cultivation (tillage) with almost no limitations.
II Mainly C slopes of good soils	Suitable for cultivation (tillage) with moderate limitations
III Mainly D slopes. Some gentler slopes of less favourable soils	Suitable for cultivation (tillage) with strong limitations
IV Mainly E slopes some D slopes	Suitable for tree crops, grasses and very limited cultivation.
V Mainly E and F slopes	Not suitable for cultivation but suitable for planted forest, tree crops and improved grass.
VI Mainly steep rocky land or dry climate	Not suitable for cultivation. Suitable for poor forest.
VII Rock outcrops, riverwash, etc.	Little or no productive use.

Soil Group	Soils in Group
A1	34, 36
A2	46
A4	33, 98
A5	50, 51
A6	96
A7	32, 35, 59, 95
B1	78
B3	74, 75, 94
B4	77
C1	6, 106
C3	7, 8, 61, 63, 66, 79
C6	11, 24
C7	12, 14
C8	13

Within the system used to determine land capability in Jamaica slope is, in most cases the primary factor. The need to align this with the detailed soil survey requires further subdivision within each class. Four principle limiting factors are counted sufficiently important to be indicated by a subscript following the land capability number. These are:

'e' if the limiting factor is slope or erosion,

'w' if there is excess water in the soil seasonally or otherwise,

's' if it is a soil factor implying usually shallow or droughty soil,

and 'c' if for climatic reasons there is a shortage of water.

Land Capability Classification of the Soil Groups and Slope Classes

Soil Group	Slope Classes					
	A	B	C	D	E	F
Soils on shale, conglomerate or igneous rocks:						
A1 Thin soils on purple or volcanic conglomerate	-	-	IIe	IIIe	IVe	Ve
A2 Thin soils on shale	-	-	IIe	IIIe	IVe	Ve
A4 Poorly drained upland clays, mottled subsoil	-	IIw	IIw	IIIe	IVe	-
A5 Soils on granitic rocks or porphyry	-	-	IIIe	IVe	Ve	Ve
A6 Soils on sandstones and gravels	-	-	IIIe	IVe	Ve	Ve
A7 Soils on deeply weathered tuffs or conglomerate	IIs	IIs	IIIe	IVe	Ve	Ve
Soils on limestone:						
B1 Bauxite	IIIs	IIIs	IIIe	IIIe	IVe	Ve
B3 Moderately deep brown soils	-	IIw	IIe	IIIe	IVe	Ve
B4 Very thin brown or reddish soils on hard limestone	-	-	Vs	Vs	VIs	VIs
Soils of coastal plains, inland basins and alluvial valleys:						
C1 Moderately drained soils over sand and gravel	IIIc	IIIc	IIIc	-	-	-
C3 Imperfectly or poorly drained soils in basins	IIw	IIw	IIe	IIIe	-	-
C6 Well drained light soils on recent alluvium	I	I	IIe	-	-	-
C7 Well drained heavy soils on recent alluvium	I	I	IIe	-	-	-
C8 Poorly drained heavy soils on recent alluvium	IIIw	IIIw	IIIw	-	-	-

APPENDIX G

Comparison of Air Photo Interpretation and Ground Data for Traverse Points

Comparison of Air Photo Interpretation and Ground Data for Traverese Points

Position Number	Soil Type	Slope	Land Use		Erosional Status		Capability Class
			Photo	Ground	Photo	Ground	
1	24	A	1e	1e	none	none	I
2	61	C	3b	3b	on slopes	stabilised	IIe
3	74	B–C	3	1b+3	on slopes	stabilised	IIw/e
4	77	E	2f/7	2f/7	active on slopes	appears stabilised but crops poor	Ve
5	51/50	C–F	2f/7	2F/7	active	active	IIIe–Ve
6	RW–50	A–F	2f/7	2f/7	active	active	VII–Ve
7	50	E–F	2f/7	2f/7	not evident	not evident	Ve
8	50	E–F	2f/7	2f/7	not evident	roadside only	Ve
9	50	E–F	2f/7	2f/7	none	none	Ve
10	77/75–6–24	A–E	Mixed	Mixed	eroded river terrace	river terrace stabilised	I–IIIe
11	61–24	A–D	1a	1a	stream bank	stream bank	I–IIIe
12	24	A	1a	1a	stream bank	stream bank	I
13	61	C	8/7	Playground	indications	some soil loss	–
14	61–75	C–D	2f	cemetary & road banks	indications	old features by quarry(?) new feature along road	IIe
15	61	C–D	3b/6	thin pasture	sides of depressions	continuing problem	IIe

Position Number	Soil Type	Slope	Land Use		Erosional Status		Capability Class
			Photo	Ground	Photo	Ground	
16	61–77/75	C–F	2f/8	scrub/fallow	active on slopes	nolonger active	IIe–Vs/IIIe
17	61	C–F	Bauxite Works	Bauxite Works	severe in places	severe in places, gully-ing	IVe/Vs
18	34–77/75	D–F	6–1b/1a	1a + mixed	none	stabilised	IV/Ve–Vs/IVe
19	61	C–D	1a	1a	on break in slope	stabilised	IIe/IIIe
20	13	A	1a	1a	none	none	IIIw
21	75	C–D	3b	1b	active on slopes	active on slopes	IIe/IIIe
22	61	C	3b	3b	along streams	stabilised	IIw
23	61–75	D	2f/7	2a/7	none evident	bank erosion	IIIe
24	63–61–11	B–D	1a/e/6	3b	stream banks + higher slopes	stream banks and higher slopes	IIw
25	94/95	E	2f	2f	none	none	IVe/Ve
26	94	D	2f	2f	none	none	IIIe
27	34	E–F	3/6	3/6	roadside	hillside rilling and gullying, recent	IVe/Ve
28	77/78	D–F	2f/7	2f/7	none	severe	VIs/IIIe
29	78	C–D	1a	1a	none	minor features on slopes	IIe/IIIe
30	77/78	D–F	2f/7	2f/7	active	active	VIs/IIIe

Position Number	Soil Type	Slope	Land Use		Erosional Status		Capability Class
			Photo	Ground	Photo	Ground	
31	77/78	D-F	2f/6	2f/7	on hill tops	almost total loss of soil on hilltops	VIs/IIIe
32	77/78	D-F	6/3	2f/6	on steep slopes	hillsides scarred	VIs/IIIe
33	106	B	1a	1a	continuing but minor problem	continuing but minor problem	IIIc
34	106	A-B	1a	1a	none evident	bank erosion	IIIc
35	106	B	1a	1a	bank erosion	bank erosion	IIIc
36	13/106	B	1a	1a	bank erosion	bank erosion	IIIc/IIIw
37	77/78	C-F	2f/7	2f/7	none	none	IIIe/Vs
38	33	C	Factory	Factory	none	slight	IIw
39	77/78	D-F	2f/6	2a/6	none	past problem now stable	IIw/IVs
40	77/78	D-F	2f/6	2f/6	on slopes	on slopes	VIs/IIIe
41	77	F	1a	2a	roadside slopes	slight problem	VIs
42	77/78	D	2f	2f/7	none evident	very thin soils	Vs/IIIe
43	32	C	2f/7	2f/7	slight indications	very thin soils	IVe/Ve
44	77/75	E-F	2f/6	2f/7	on slopes	soil loss on slopes	VIs/Ve

APPENDIX H

Conversion codes used to carry out digitising on the Hewlett-Packard 9874A Digitizer linked to the 9825A Desktop Computer.

Conversion Table for Soil and Slope to Digitiser Codes (digits 1,2 & 3)

Soil/Slope	Code No.	Soil/Slope	Code No.	Soil/Slope	Code No.
6A	1	33B	36	51E	71
6B	2	33C	37	51F	72
6C	3	33D	38	59A	73
6C/D	4	33E	39	59B	74
7A	5	33B/C	40	59C	75
7B	6	34C	41	59D	76
7C	7	34D	42	59E	77
7D	8	34E	43	59F	78
8A	9	34F	44	61A	79
8B	10	34E/F	45	61B	80
8C	11	35A	46	61C	81
8D	12	35B	47	61D	82
11A	13	35C	48	61C/D	83
11B	14	35D	49	61C/75D	84
11C	15	35E	50	61D/75D	85
12A	16	35F	51	61D/77E	86
12B	17	35D/E	52	63A	87
12C	18	35/36	53	63B	88
12A/B	19	36C	54	63C	89
13A	20	36D	55	63D	90
13B	21	36E	56	66A	91
13C	22	36F	57	66B	92
14A	23	36E/F	58	66C	93
14B	24	46C	59	66D	94
14C	25	46D	60	66/75D	95
24A	26	46E	61	74B	96
24B	27	46F	62	74C	97
24C	28	50C	63	74D	98
32A	29	50D	64	74E	99
32B	30	50E	65	74F	100
32C	31	50F	66	74B/C	101
32D	32	50D/E	67	75B	102
32E	33	50E/F	68	75C	103
32F	34	51C	69	75D	104
32C/E	35	51D	70	75E	105

Soil/Slope	Code No.	Soil/slope	Code No.	Soil/Slope	Code No.
75F	106	78D	141	98D	176
75C/D	107	78E	142	98E	177
75D/E	108	78F	143	106A	178
75E/75C/D	109	78E/F	144	106B	179
75/77C	110	79A	145	106C	180
75/77D	111	79B	146	RW	181
75/77E/F	112	79C	147	10B	182
75C/77D	113	79D	148	10C	183
75D/77E	114	94B	149	64A	184
75D/77F	115	94C	150	64B	185
75E/77D	116	94D	151	64C	186
75F/77E	117	94E	152	64D	187
75D/77E/F	118	94F	153		
75C/D/77D	119	94C/D	154		
75E/D/77E	120	94D/E	155		
75C/D/77E/D	121	94/95D	156		
77C	122	94/95E	157		
77D	123	94E/95	158		
77E	124	94/96D	159		
77F	125	94E/96D	160		
77E/F	126	95A	161		
77/78D	127	95B	162		
77E/78D	128	95C	163		
77F/78D	129	95D	164		
77E/78	130	95E	165		
77E/78D/C	131	95F	166		
77F/78C/D	132	95D/E	167		
77E/F/78D	133	95/96D	168		
77/94F	134	95D/96E	169		
77/94E/F	135	96C	170		
77E/95D	136	96D	171		
77E/F95D	137	96E	172		
78A	138	96F	173		
78B	139	98B	174		
78C	140	98C	175		

Conversion Table for Land Use Codes to Digitiser Codes (digits 4 & 5)

Land Use Code	Code No.	Land Use Code	Code No.
1a	01	2d	22
1b	02	2e	23
1c	03	2f	24
1d	04	2a/f	25
1e	05	2b/e	26
1f	06	2e/f	27
1a/e	07	2e/3	28
1b/e	08	2f/6	29
1c/e	09	2f/7	30
1a/6	10	2f/8	31
1a/7	11	3	32
1a/8	12	3a	33
1a/3/7	13	3b	34
1b/7	14	3/6	35
1b/8	15	3/7	36
1e/2f	16	3/8	37
1e/3	17	3a/6	38
1e/6	18	3b/6	39
2a	19	6	40
2b	20	7	41
2c	21	8	42

APPENDIX J

Land Use Recommendations

The numbers and codes used in the following tables of land use recommendations are those used throughout this study. For convenience, however, the land use classification and slope classifications are included here.

Where a low intensity land use, such as food forest (7), has been observed on a particular soil/slope combination on the aerial photographs it has been included within the recommendations (see soil type 6). Where a low intensity use has not been observed it has not been included. For example on soil type 8 no food forest was observed on the shallower slopes, but high intensity uses such as plantation sugar (1a) were observed and included within the recommendations. Where this has happened it would also be safe, in terms of erosion risk, to use the land for food forest or some other low intensity usage. These lower intensity uses can, therefore, be inferred to be suitable even though they are not listed. To use the land for low intensity usages when it is suitable for high intensity usage would, however, not make economic sense.

These recommendations do not necessarily agree with those given in the Soil and Land Use Survey (Vernon and Jones, 1958) since these recommendations are based upon what it can be shown to be safe to grow, in terms of erosion hazard. It might, however, be inadvisable to grow certain crops listed here because the soil is physically or chemically unsuitable, because it drains too freely or does not drain freely enough. All that can be said is that cultivating them will not cause an erosion problem if cultivation is carried out properly, with due regard for the simple conservation measures listed in Chapter 9.

Where a usage has been listed in parenthesis this implies that that particular high intensity usage was not observed on the soil in question, but that there are no reasons why that usage should create an erosion problem on the soil in question (see soil type 11).

TABLE J.1 Land Use Classification
(Developed for use in this research programme)

1. Plantation
   a. Sugar)
   b. Citrus)
   c. Banana) Pure Stand
   e. Palm)
   d. Other
   f. Mixed Stand (or use combination of two from above)

2. Cultivation - Subsistance, Horticulture and Market Gardens
   a. Sugar)
   b. Citrus)
   c. Banana) Pure Stand
   d. Palm
   e. Other
   f. Mixed

3. Grassland and Pasture (including scrub pasture land)
   a. Improved
   b. Unimproved

4. Fallow

5. Ruinate
   a. Used as Pasture
   b. Other

6. Woodland

7. Food Forest

8. Urban, Industrial and other non-agricultural land use

9. Swamp and Marshland

TABLE J.2 Slope Classes used in St. Catherine Soil Survey (after Vernon and Jones 1958)

Slope Class	Slope Gradients
A	0°-2°
B	2°-5°
C	5°-10°
D	10°-20°
E	20°-30°
F	Over 30°

SOIL TYPE	SLOPE CLASS A	B	C	D	E	F
6	1a,1b,3a,7 2f(1c,1e)	1a,1b,3a,7 24(1c,1e)	1b,3a,7,24 (1c,1e)	–	–	–
8	1a,1b,1e,2f 3a(1c)	1a,1b,1e,2f 3a(1c)	1a,1b,1e,2f 3a(1c)	1b,1e,2f 3a	– –	– –
11	1a,1b,2f,3a (1c,1e)	1a,1b,2f,3a (1c,1e)	1b,2f,3a (1e)	–	–	–
12	1a,1b,1e,2f 3a,7	1a,1b,1e,2f 3a,7	–	–	–	–
13	1a,1b,2f,3a	1a,1b,2f,3a	1b,2f,3a	–	–	–
14	1a,1b,1e,2f 3a	1a,1b,1e,2f 3a	–	–	–	–
24	1a,1b,1c,2f,3a 1e	1a,1b,1c,1e,2f 3a	1a,1b,1c,1e,2f 3a	–	–	–
32	1b,2f,7	1b,2f,7	2f,7	2f,7,6	7,6	6
33	–	1b,1a,2f,3a 7	1b,2f,3a,7 1a	1b,2f,3a,7	7,6	6
34	–	–	1a,2f,3a,7	2f,3a,7,6	7,6,3a,2f	6,7
35	2a,2f,7	2a,2f,7	2a,2f,7	2a,2f,7	2f,7	7
36	–	–	1b,2f,7,2a	2a,1b,2f,7	2f,7,6	7,6
46	–	–	3a,7	3a,7	7,6	7,6
50	–	–	2f,7,3a	2f,7,3a	2f,7	7,6
51	–	–	1e,2f,7	2f,7	2f,7	7
61	1a,1b,1e,2f 3a	1a,1b,1e,2f 3a	1a,1b,1e,2f 3a	1e,2f,1b 7	–	–

SOIL TYPE	SLOPE CLASS A	B	C	D	E	F
63	1b, 2f (3a)	1b, 2f (3a)	1b, 2f (3a)	7, 2f	-	-
66	3a, 7	3a, 7	3a, 7	7	-	-
10	2f, 7 (1b, 3a, 1c, 1e)	2f, 7 (1b, 1c, 1e, 3a)	2f, 7 (1b, 1c, 1e, 3a)	-	-	-
64	1, 2f, 7	1, 2f, 7	1, 2f, 7	2f, 7		
74	-	1a, 1b, 1e, 2f, 3a	1a, 1b, 1e, 2f, 3a	1b, 1e, 2f, 3a	2f, 3a, 7	7, 6
75	- 2f	1b, 1e, 3a, 2f	1b, 1e, 3a 7, 6, 2f	1e, 3a, 1b, 1a	2f, 7, 6	7, 6
77	-	-	2f, 6, 7	2f, 6, 7	6, 7	6.7
78	1a, 2f, 3a	1a, 2f, 3a	1a, 2f, 3a	3a, 6, 7	3a, 6, 7	6, 7
79	2f, 7, 6	2f, 7, 6	7, 6	7, 6	-	-
94	-	2a, 2f, 3a	2a, 2f, 3a	2a, 2f, 3a, 7	2f, 3a, 7, 6	7, 6
95	2a, 2f, 3a 1c	2a, 2f, 3a 1c	2a, 2f, 3a 1c	2a, 2f, 3a 1c	2f, 7, 3a	7, 6
96	-	-	2f, 7 (3a)	2f, 7 (3a)	2f, 6, 7 (3a)	6, 7
98	-	2a, 2f, 1c (3a)	2a, 2f, 1c (3a)	2f (3a, 7)	(3a, 7)	-
106	1a, 1b, 3a, 1c	1a, 1b, 3a, 1c	1a, 1b, 3a, 1c	-	-	-

APPENDIX K

Cross tabulations and other tables used in the analysis of the data to determine the relative effects of soil type, slope and land use on the rate of erosion.

CROSS TABULATION OF LAND USE BY SLOPE

(SLOPE CLASSES AGGREGATED DOWN)

LAND USE	SLOPE CLASSES					
	A	B	C	D	E	F
1a	12	15	20	17	6	2
1b	11	15	17	12	7	1
1c	2	2	2	4	1	0
1e	8	9	10	10	3	2
1f	1	0	1	2	0	0
1a/e	2	5	7	6	1	1
1b/e	2	7	4	3	0	0
1c/e	4	1	2	1	0	1
1a/7	2	3	3	9	3	1
1a/8	0	0	1	1	1	0
1a/3/7	0	1	2	2	1	1
1b/7	0	0	1	0	0	0
1b/8	0	1	1	2	0	0
1e/2f	0	1	1	3	1	0
1e/3	1	1	2	2	1	0
1e/6	0	1	1	2	0	0
2a	0	4	2	3	3	2
2b	1	6	8	11	5	0
2d	0	1	0	0	0	0
2e	0	0	1	1	0	0
2f	6	9	14	17	11	5
2a/f	0	4	7	12	7	4
2b/e	0	2	2	1	0	0
2e/f	0	1	1	1	0	0
2e/3	0	0	0	1	0	1
2f/6	4	10	10	17	13	2
2f/7	6	14	24	35	16	7
2f/8	2	5	4	5	6	0
3	3	6	7	11	6	2
3a	3	6	6	7	1	0
3b	2	4	4	6	3	1
3/6	3	10	8	15	10	4
3/7	2	1	7	8	9	3
3/8	0	0	1	2	1	0
3a/6	0	0	3	0	1	0
3b/6	0	0	0	0	1	0
6	6	13	15	18	11	3
7	3	6	8	12	8	1
8	2	1	3	8	1	0

CROSS TABULATION OF LAND USE BY SLOPE

(SLOPE CLASSES AGGREGATED UP)

LAND USE	SLOPE CLASSES					
	A	B	C	D	E	F
1a	11	15	14	13	10	9
1b	10	14	13	12	8	6
1c	2	2	2	3	1	1
1e	7	9	7	7	5	7
1f	1	0	1	1	0	1
1a/e	2	5	5	6	3	1
1b/e	1	8	4	2	0	1
1c/e	4	1	2	0	0	2
1a/7	2	3	3	6	3	4
1a/8	0	0	1	1	1	0
1a/3/7	0	1	1	0	3	2
1b/7	0	0	1	0	0	0
1b/8	0	1	1	1	1	0
1e/2f	0	1	1	2	1	1
1e/3	1	1	1	3	1	0
1e/6	0	1	1	1	1	0
2a	0	4	1	3	2	4
2b	1	6	4	10	4	6
2d	0	1	0	0	0	0
2e	0	0	1	0	0	1
2f	6	9	10	4	10	13
2a/f	0	4	6	10	7	7
2b/e	2	2	2	1	0	0
2e/f	0	1	1	1	0	0
2e/3	0	0	0	0	0	2
2f/6	4	9	6	12	15	10
2f/7	6	14	18	27	21	16
2f/8	2	5	4	4	4	3
3	3	5	6	8	4	9
3a	3	6	5	5	2	2
3b	1	5	2	6	3	3
3/6	3	10	4	11	9	13
3/7	2	1	5	8	7	7
3/8	0	0	1	0	1	2
3a/6	0	0	1	2	1	0
3b/6	0	0	0	0	1	0
6	6	12	12	13	12	11
7	3	6	7	7	10	5
8	2	1	3	5	2	2

Soil No.	% of Soil Eroded	Soil as % of Study Area	Erosion as % of Total Erosion
6	1.97	0.70	0.90
7	8.27	0.06	0.32
8	0.78	0.81	0.41
10	2.86	0.04	0.07
11	3.32	0.60	1.30
12	0.82	1.13	0.61
13	3.81	0.93	2.31
14	3.06	0.25	0.51
24	1.88	1.15	1.41
32	0.40	0.07	0.02
33	2.19	2.08	2.98
34	0.63	11.28	4.60
35	1.42	1.30	1.19
36	3.26	0.85	1.81
46	0.00	0.02	0.00
50	1.47	11.75	11.27
51	0.00	0.12	0.00
59	0.00	0.02	0.00
61	1.91	12.52	15.52
63	17.36	0.20	2.10
64	0.00	0.12	0.00
66	2.27	0.17	0.26
74	2.23	0.77	1.11
75	2.02	3.20	4.20
77	1.23	3.41	2.72
78	0.92	1.11	0.66
79	0.92	0.06	0.04
94	0.54	0.97	0.34
95	0.33	1.75	0.37
96	1.24	0.03	0.02
98	0.34	0.06	0.01
106	0.96	0.92	0.57
RW	0.42	0.38	0.10
35/36	0.28	0.32	0.06
61/75	1.12	0.89	0.65
61/77	0.78	0.07	0.04
66/75	0.00	0.01	0.00
75/77	1.48	11.01	10.56
77/78	1.54	28.65	28.68
77/94	0.00	0.68	0.00
77/95	8.09	0.27	1.41
94/95	0.64	0.24	0.10
94/96	0.00	0.06	0.00
95/96	0.60	0.15	0.06

% Erosion Mean 1.89
Standard Deviation 2.92

Land Use	% of Land Use Eroded	Land Use as % of Study Area	Erosion as % of Total Erosion
1a	4.10	8.68	22.22
1b	0.31	2.59	0.53
1c	0.00	0.10	0.00
1e	0.14	1.36	0.13
1f	0.00	0.03	0.00
1a/e	4.65	0.62	1.89
1b/e	0.00	0.19	0.00
1c/e	0.92	0.16	0.10
1a/7	3.27	0.39	0.83
1a/8	0.00	0.04	0.00
1a/3/7	0.78	0.24	0.12
1b/7	0.00	0.02	0.00
1b/8	0.00	0.02	0.00
1e/2f	0.99	0.08	0.05
1e/3	0.00	0.17	0.00
1e/6	0.00	0.03	0.00
2a	1.26	0.65	0.53
2b	0.60	0.23	0.09
2d	0.00	0.00	0.00
2e	40.24	0.01	0.30
2f	0.81	4.37	2.30
2a/f	0.99	2.54	1.64
2b/e	0.00	0.06	0.00
2e/f	0.00	0.04	0.00
2e/3	0.00	0.06	0.00
2f/6	1.66	12.50	13.51
2f/7	0.98	32.35	20.63
3, 3a, 3b	1.70	2.71	3.00
3/6, 3a/6, 3b/6	2.00	13.76	17.90
3/7	1.94	2.22	2.81
3/8	0.00	0.04	0.00
6	0.99	13.19	8.47
7	2.36	1.28	1.96
8	3.28	0.19	0.41

% Erosion Mean = 2.13
Standard Deviation = 6.80

APPENDIX L

Examples of Soil Conservation Legislation

THE LOCAL ADMINISTRATION LAW (Chapter 77)

THE JOS LOCAL ADMINISTRATION (BURNING OF BUSH) ORDER 1966

Date of Commencement.....................................

NORTHERN REGION PUBLIC NOTICE

THE NATIVE AUTHORITY LAW, 1954, (No. 4 of 1954)

THE PANKSHIN FEDERATION NATIVE AUTHORITY (CONTROL OF SOIL EROSION) RULES, 1958.

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