AGROFORESTRY MEASURES FOR SOIL CONSERVATION IN HILL SLOPE

By

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THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Science in Agriculture

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Kerala Agricultural University

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COLLEGE OF HORTICULTURE
Vellanikkara - Trichur
Kerala - India

1989

DECLARATION

I hereby declare that this thesis entitled 'Agroforestry measures for soil conservation in hill slope' is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Vellanikkara,
16-8-1989.

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CERTIFICATE

Certified that this thesis entitled 'Agroforestry measures for soil conservation in hill slope' is a record of research work done independently by Sri.ALI, P. (Admn. No.85-11-12) under my guidence and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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ACKNOWLEDGEMENT

I wish to place on record my deep sense of gratitude and indebtedness to Dr.C.Sreedharan, Dean, Faculty of Agriculture, Kerala Agricultural University, Trichur and Chairman of the Advisory Committee for his memorable and invaluable guidence, inspiration and constant encouragement during the course of my investigation and in the preparation of the thesis.

I also avail myself this opportunity to express my heartfelt thanks to Dr.R.Gopinathan, Associate Professor, Kerala Agricultural University and Member of the Advisory Committee for the generous investment of time, right from the beginning to the end of the study.

Sincere thanks are also due to Sri.V.R.Krishnan Nair, Special Officer, Forestry, Kerala Agricultural University and Prof.T.P.George, Dean i/c. Faculty of Agrl. Engineering, the other Members of the Advisory Committee for their constructive suggestions and encouragements throughout.

A special note of thanks goes to Dr.V.K.Venugopal, Associate Professor, College of Horticulture, Vellanikkara for his valuable advices at various stages of the chemical analysis.

It is with great pleasure, I acknowledge the help rendered by Sri.T.P.Ravi Prasad and Sri.E.G.Ranjithkumar in preparing the illustrations.

As a final note, I wish to record my appreciation and thanks to all my wellwishers and friends who helped me in some way or other in bringing out this thesis successfully.

ALI, P.

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Introduction

INTRODUCTION

Soil erosion, apart from the ecological threat, is a serious economic problem also. The gravity of this problem is so acute that the very existence of man is in danger, if the present rate of erosion continues unabated. About 5 to 7 million ha of good quality land is being lost every year from all over the world (Kovda, 1974). India is annually lossing 6000 million tonnes of fertile top soil amounting to 2.5, 3.8 and 2.6 million tonnes of N, P_2O_5 and K_2O respectively which is much greater than the annual addition of these nutrients through fertilizers (Kanwar, 1982). Characterised by its undulating topography, intense rainfall, acute pressure on available land and unscientific cultivation of hill slopes, soil erosion problem is so severe in Kerala.

The broad categories of land management available for soil and water conservation are mechanical and biological measures. The most widely adopted mechanical measures like bunding and terracing are characterised by drawbacks such as high cost, arduous nature, and limited adaptability with the existing farming situations, which discourage the hill slope farmers in adopting them to any considerable extent. Further, in its wider sense soil conservation involves not only control of erosion, but also maintenance of fertility. Agroforestry has been widely accepted as an economically and ecologically viable land management programme for effective soil conservation in this sense. It is a sustainable system to optimize the resources of grain, forage, timber, animal products as well as to conserve the soil and nutrients (Singh, 1988).

Most of the research results now available in agroforestry are from temperate zones and the knowledge of the system in tropical climate, soil and ecosystem is rather inadequate (Kanwar, 1982). Especially because of expansionistic as opposed to the deterministic nature, it is also difficult to transfer the technologies from one situation to another (Nair, 1983). Region specific or even site specific technologies need to be generated to suit the local environmental conditions and farming systems. In Kerala the research on this line is still at the infant stage.

Good crop management can be upto ten times more effective in reducing the amount of erosion than any advanced mechanical practices like terracing or bunding. This is mainly because of the importance of crop cover in reducing the effects of raindrop impact on the soil. Shaxson (1981) suggests that the effect of vegetation is so enormous that more effort should be made to integrate crop cover with other soil conservation works.

Cassava, the most preferred taungya crop was found to cause an erosion as high as 300 t of rich top soil per ha per year from a land of 25 per cent slope (Gopinathan, 1986). Irrespective of the severe soil depleting nature of cassava, large and increasing number of small and marginal farmers in the foot hills of Kerala are cultivating cassava extensively. This will invariably result in the degradation of a vast majority of lands. Since cassava will continue as an inevitable crop component of subsistance agriculture, it is high time to develop conservation techniques compatible to the farming systems of the hill slopes. Hence to develop ecologically and economically viable package technologies for steep hill slopes, the present study was undertaken with the following objectives.

(1) To quantify the run-off and soil loss as influenced by different agroforestry practices.

(2) To estimate the loss of N, P and K as influenced by different treatments.

(3) To work out the economics of each system.

(4) To identify an economically and ecologically viable agroforestry system for steep hill slopes of Kerala.

Review of Literature

REVIEW OF LITERATURE

1. Soil erosion

The vastly accelerated process of soil removal brought about by human interference with the change in equilibrium between soil building and soil removal is designated as soil erosion. When erosion results only from the forces of nature, it is geological or normal erosion and when the process results from human interference, it is designated as accelerated erosion (Hudson, 1984).

The severity of this problem is so great that about 5-7 million ha of good quality land is being lost every year from all over the world (Kovda, 1974). In India, out of the total geographical area of 328 million ha, about 172 million ha are subjected to varying forms of soil erosion with water erosion contributing to 90 million ha (Datta, 1986). Due to its undulating topography coupled with very high intense seasonal rainfall, Kerala has severe erosion problems in more than 50 per cent of its cultivable area. According to the report of Kerala State Planning Board (1984) about 1.5 million ha are subjected to erosion hazards out of which only 0.075 million ha could be brought under conservation measures.

2. Erosion by water

A major part of erosion occurs through water resulting from the action of rain on soil (Hudson, 1977). Erosion can be represented as a function of erosivity of rainfall and erodibility of soil. Erosivity is the potential ability of the rain to cause erosion, while the vulnerability of a soil to erosion is designated as erodibility (Hudson, 1977).

With each successive rainfall on bare soil, the infiltration rate is reduced due to the increased blockage of macropores by the detached and translocated soil particles. Then the run-off point occurs, leading to erosion (Yadav, 1961 and Uriyo, 1979).

Run-off transports particles as bed load and suspended load depending on flow hydraulic and sediment characteristics. Raindrop impact significantly increases the transport capacity of shallow, sheet flow and lifts large particles into the overland flow, so that flow can move them short distances before they settle back (Foster and Meyer, 1977). High correlation of run-off with rainfall was observed by Gopinathan (1986).

3. Erosivity

Erosivity is specifically and solely a property of the rainfall (Hudson, 1977). The aggressivity or erosivity of rainfall is a function of its physical characteristics such as total amount, intensity, kinetic energy etc. (Wischmeier and Smith, 1958; Hudson, 1984). Eventhough an obvious relationship exists between the amount of rainfall and soil erosion, this should not be true in all the cases.

3.1. Amount and intensity of rainfall

The total amount of rainfall does not give the true rainfall characteristics of a place. The distribution of rainfall is important which would indicate the quantities downpour (Datta, 1986).

Tropical rains are more erosive than temperate ones due to their high intensities. Both amount and intensity influence the erosivity of rainfall (Husdon, 1984 and Verma, 1984). Khybri et al. (1985) reported that rainfall amount showed highest correlation with soil loss under Dehradun conditions. According to Datta (1986), intensity is the most important rainfall characteristic affecting erosion. Maximum intensity of rainfall found to be highly correlated with erosion (Gopinathan, 1986).

3.2. Energy relationships

Wischmeier (1955) observed that the factor most closely related to erosion was the kinetic energy of the rain. Kinetic energy of a raindrop is related to its terminal velocity which in turn is a function of drop size distribution (Wischmeier and Smith, 1960).

The total kinetic energy of a storm is determined by the intensity of the particular storm and the erosive power of the rainfall is related to its total kinetic energy. Yadav (1961) calculated the total kinetic energy of a rain of intensity 5 cm hr^{-1} as 250 hp on an acre of land.

Experimental evidences are there to prove that erosive power of rainfall is related to compound parameters derived from combinations of more than one physical property such as momentum, kinetic energy etc. (Free, 1960). Rose (1960) argues that momentum is more related than kinetic energy with erosivity of rainfall. However Hudson (1984) showed that for natural rainfall the relationship between intensity and either momentum or kinetic energy are of similar form. Gopinathan (1986) obtained strong correlation for kinetic energy (0.822) with erosion.

3.3. Erosivity Indices

Many researchers indicated that either rainfall amount or intensity is not highly correlated with soil loss and run-off. Attempts were made to evolve a combination of different rainfall parameters so that it would be a better index of erosivity than either the amount or the intensity. Consequently several indices were developed and are mainly situation specific. The most widely used index is EI_{30}, developed by Wischmeier and Smith (1958). It is the product of one hundredth of kinetic energy of the storm in mt ha^{-1} cm^{-1} and maximum 30 minutes rainfall intensity in cm hr^{-1}. Similarly EI_{15} and EI_5 are also in use. Barnet (1958) used EI_{60} and obtained a clear correlation of EI_{60} with soil loss.

Hudson (1971) developed $KE > 1$ index for Zimbabve. It is the cumulative kinetic energy of storms with intensity greater than 2.5 cm hr^{-1}. According to him, storms with intensity less than 2.5 cm hr^{-1} are not erosive. Lal (1976) developed still another index (AIm) which is the product of total rainfall amount and peak storm intensity, found to be highly correlated with run-off in Nigeria. Viswambaran (1980) also reported good correlation of run-off with AIm. Hudson (1984) pointed out that, though EI_{30} be appropriate for many temperate regions, it may not be suitable for tropical regions.

Viswambaran (1980) reported EI_{15} and EI_5 as best indices in estimating soil loss. Gopinathan (1986) also observed the validity of EI_{15} in estimating soil loss under Kerala conditions.

4. Erodibility

The erodibility of a soil is its vulnerability or susceptibility to erosion. It is a function of both physical characteristics and management of a soil (Hudson, 1984). Soils vary greately in their origins and manner of formation as well as in their management.

According to Datta (1986) soil erodibility is determined by a combination of soil physical and chemical characteristics. Chemical properties such as pH, Organic Carbon, CEC etc. have great influence over physical properties and, therefore, affect the erodibility of soil. A highly erodible soil may erode 10 times faster than a less susceptible soil exposed to the same moderate to intense rainfall (Wischmeier et al., 1971).

Topography plays an important role in soil erosion. Micro and macrotopography each influences erosion and sediment delivery from farm fields and from other similar upland sources (Foster and Meyer, 1977). Microtopography is expressed by steepness, length and shape etc. Both steepness and length of slope contribute to erosion and run-off. Increased soil loss and run-off with increase in steepness of slope were reported by many workers from many countries (Bala Subramanian and Sivanappan, 1981; Subhash Chandra and Rao, 1984a). Similarly greater soil loss was reported from longer slopes. However, there are reports of decreasing soil loss with increase in length on gentle slope beyond a limit (Subhash Chandra and Rao, 1984b).

5. Impact of erosion on soil fertility

Kanwar (1982) reported that, India is annually losing about 2.5, 3.8 and 2.6 million tonnes of N_2, P_2O_5 and K_2O respectively through erosion. However it has been emphasised that well managed lands under efficient crop rotation would have lesser or no N_2 losses as compared with fallow, poorly managed lands (Jayaram et al., 1984).

Under tropical and subtropical conditions P_2O_5 loss due to erosion may not be much (Singh and Biswas, 1982).

The eroded materials have more K than N and P since K contents are higher in soil (Kanwar, 1982). Effective crop rotation and grass cover reduces K loss through eroded soil to negligible levels (Jayaram et al. 1984).

Gopinathan (1986) reported a loss of 416 kg N, 116 kg P and 680 kg K per ha through eroded soil in tropical humid climate of Kerala for oxisolic soils.

6. Conservation measures

Attempts have been made by several workers to assess the tolerable limit of soil loss, that permits sustained crop productivity, economically and indefinitely (Hudson, 1971, Bertoni et al., 1975 and Lal, 1984). Consequently different values were evolved in different countries depending on the soil conditions. For tropical countries Requier (1982) suggested a soil loss tolerence of 10 t ha^{-1} yr^{-1}. According to him, whenever the soil loss exceeds this limit, supporting conservation measures are to be adopted.

The two broad categories of land management available for soil and water conservation are mechanical and biological measures (Dhruvanarayana, 1987). Hudson

(1971) observes that mechanical and biological measures are not two alternatives, but are complimentary to each other.

Bunding and terracing are most widely adopted mechanical measures in soil and water conservation programme. These practices help in reduction of erosion due to overland flow during high storm rains (Datta, 1986). Biological measures include contour cultivation, vegetative buffers and barriers, cover plants etc. (Webstor and Wilson, 1975; Nair, 1984 and Randhawa, 1988).

7. Performance of Biological measures in comparison with mechanical measures

To have a better understanding about this, we should consider the Universal Soil Loss Equation developed by Wischmeier and Smith (1978). In this equation (A = RKLSCP) the humanly controllable variables are slope length (L), crop management (C) and conservation practices (P). By resorting the improved methods, both L and P values can be reduced to half resulting in a halving of soil loss by the reduction of either one of this (Hudson, 1984).

The effect of crop management is very different. While the worst practice has a 'C' value of 1.00, the good practices have 'C' values as low as 0.05. From this it is clear that good crop management can be upto ten times more effective in reducing erosion than any other measures. Further the conventional soil conservation measures in the form of terraces are costly and take time to complete (Menon, 1984).

If soil conservation measures are to be successful, they must be taken up by the farmers and should be compatible with the current farming system (Hudson, 1984 and Morgan, 1985). According to Randhawa (1988), though mechanical and vegetative measures are important, mechanical structures are not alternatives to vegetative measures.

Various limitations of mechanical measures were also discussed by several workers. High installation costs, practicability under high rainfall and steep slope conditions, considerable loss of cultivable area and maintenance cost form major limitations in several cases (Highfill and Kimberlin, 1977; Datta, 1986 and Dhruvanarayana, 1987).

These highlight the importance of agronomic measures of soil conservation.

8. Agronomic measures of soil conservation

Agronomic measures relate to the role of crop cover and soil management including tillage practices and use of fertilizers, mulches etc. Shaxson (1981) opinioned that the effects of crop cover are so enormous that more effort should be made to integrate crop cover with other soil conservation works.

8.1. Conservation tillage

Fenster (1974) emphasise the conservation tillage as a relatively new concept designed to reduce energy requirements, decrease soil erosion, increase water intake while maintaining normal yields.

Bacumer and Bakermans (1973) established the positive effect of minimum tillage on decreasing run-off and soil erosion in a field of corn without reduction in yield compared to conventional tillage. Cannell and Weeks (1979) suggested chemical fallow as one of the conservation tillage which involves control of weeds and conservation of soil and water in a crop rotation with minimum disturbance of crop residues and soil. Availability of ideal herbicides seems to be a limitation.

Dual zone cultivation was found appropriate for row crops (Cannell and Weeks, 1979). Here a fine tilth is developed in the seed bed, while the inter-row area is left in a rough cloddy state to maximize infiltration and run-off.

Hudson (1984) reported the practice of minimum tillage in America involving reduced number of operations by planting directly after ploughing without any of the intervening cultivations which are usually carried out to give a fine seed bed. Mutchler et al. (1985) also recommended conservation tillage for better soil conservation.

Mittal et al. (1986) observed that formation of ridges and furrows at sowing of maize reduced run-off by 86 per cent, soil loss 95 per cent with an increase in yield of 59 per cent.

8.2. Contour cultivation

On gentle slopes it may be sufficient to slow down surface run-off by carrying out all tillage operations on the contour (Hudson, 1984). This avoids furrows and depressions running down the slope and inviting run-off to concentrate in these with the result of causing scour erosion.

When normal cultural operations are performed across the slope, the furrows left behind, by the operations form natural ridges and channels into which the run-off accumulates. So a multitude of mini-barriers will be formed by this. According to Dhruvanarayana (1987) contour cultivation remains most effective measure only on the moderate slopes of 2 to 7 per cent, while both on flat or steep slopes, the effectiveness is less.

8.3. Mulching

Mulching with grass, weeds, brush wood or other vegetable trash protects the soil from sun and rain (Webstor and Wilson, 1975). This slows down the movement of water over the surface and improves the permeability of the soil. Unger (1975) studied with different mulches like, crop residues, leaves, clippings, bark, plastic, films, paper, petroleum products, gravel and manure. He concluded that where effective soil cover was used, yield substantially increases due to improved control of erosion and run-off. Robinson (1979) and Ghidey et al. (1985) also recommended mulching.

Cannell and Weeks (1979) suggest stubble-mulch farming system for erosion control. According to them mulches other than crop residues appear to have limited use because of the unfavourable economics.

Loppings from fast growing woody perennials can be effectively utilised for mulching in an agroforestry system (Nair, 1984). Gopinathan et al. (1988) obtained a 30 per cent reduction in erosion by the use of a cowpea live mulch in cassava. In the case of live mulches, farm operations connected with growing, cutting, carrying and spreading etc. constitute costliest operations. Other disadvantages of various mulches viz. termite problems, mechanical damage to emerging crop seedlings, the possibility of weed emergence through the gaps and creation of anaerobic conditions during rainy periods have also to be taken into account (Nair, 1984).

8.4. Crop management

Experimental evidences are many to support that soil detachment hazard is inversely proportional to the resistance factor of surface covers and mulches in reducing run-off and soil loss (Robinson, 1979; Orsi, 1984 and Ghidey et al., 1985). But defective cultivation practices like mound planting of cassava without any ground cover or row planting of maize/sorghum down the slope can aggravate the process of soil erosion. Similarly closely growing crops like grass, rice and cover crop will usually suffer less erosion.

Various crop management practices such as inter cropping (Bhola et al., 1975; Bhatia, 1980 and Hudson, 1984), crop rotation (Hudson, 1984), strip cropping (Robinson, 1979, Abujamin et al., 1985), mulching (Robinson, 1979) and conservation tillage (Mutchler et al., 1985) have been recommended for reducing soil erosion.

The crop root system can also have major effects on soil erosion. Normally the fibrous root system of the grass type crops (corn, sorghum etc.) are superior to the taproot crops (soybean, cotton etc.). So the selection of crops play key role in conservation practices.

Maize, tobacco, cotton, sorghum, rice, groundnut etc. give increased density from higher plant populations. A combination of improved variety with enough fertilizer results in a dense stand, providing a better crop with reduced erosion (Hudson, 1984).

Annual crops cannot provide cover in the early season, protection at this time must be provided in other ways. Grass and forage crops grown in rotation will greately lower the erodibility of the soil (Hudson, 1984).

Debregeasia hypoleuca grass plant have roots growing fast and penetrating deep in the soil, and with very low taper rate. Its roots are therefore strong and bind the soil well even on steep slopes against the erosive powers (Singh et al., 1986). Tyagi and Koranne (1985) reported the utility of soybean genotypes 'Indore collection', IC-18750, NO:39795 etc. as inter crops in maize with soil protection against rainfall impact and with moisture conservation.

8.5. Crop cover

The protective role of crop cover in reducing the kinetic energy of falling raindrops was first recognised by Ellison (1944). With increase in crop cover, increased rainfall interception and dissipation of energy are reported by many workers (Meyer et al., 1975; Foster and Meyer, 1977 and Singh, 1984). When rainfall is intercepted, drops that directly penetrate the crop canopy account much of the throughfall kinetic energy and drops that are splashed from leaves are quite small and contain little kinetic energy (Quinn and Laflen, 1983 and Turner et al., 1984). Increased crop canopy is hence invariably associated with lesser fun-off (Lang, 1979; Costin, 1980 and Lang and Mallet, 1984) and soil loss (Megahan, 1978; Singer et al., 1980; Singh, 1984 and Krishnarajah, 1985). From grass and forage crops a vegetative cover as complete as the artificial cover of wire guaze is obtained (Hudson, 1984).

Wischmeier (1975) argues that soil erosion decreases with increasing crop canopy cover in a linear relationship. While Shaxson (1981) clearly states that the relationship is exponential, Foster (1982) favours an exponential form for mulches and crops in close proximity to the ground surface but a linear relationship for taller crops.

Uriyo (1979) observed under permenent vegetation cover, the infiltration rate was normally greater than the hydraulic conductivity of the soil. The increased moisture storage capacity of the soil provided by the transpiratory withdrawel of growing crops results in these high infiltration rates (Venkataraman, 1978).

Mishra et al. (1979) reported that run-off can be made to vary from 2.1 to 72 per cent of the rainfall by simply manipulating the leaf area index. Agnihotri et al. (1985) observedthat the increased grass cover has lead to progressive decrease in run-off. Morgan (1985) concluded that crop cover results in less surface crusting, or sealing and consequently the infiltration remains high, with low surface run-off.

Control of erosion in plantations of tree crops on land of any considerable slope usually demands the maintenance of a good ground cover especially during the establishment period (Webstor and Wilson, 1975). According to Nair (1984), the presence of more plant cover on the soil surface ensure better efficiency in the utilization of the native and applied nutrients apart from controlling erosion.

Gopinathan (1986) reported efficient controlling of erosion through grass farming in steep slopes, which reduced run-off to 4 per cent and erosion to 0.4 t $ha^{-1}yr^{-1}$.

8.6. Vegetative barriers

Permanent contour strips of grasses or shrubs may be used either alone or in conjunction with mechanical conservation measures, so that they give a dense and continuous cover, slow-down run-off and cause deposition of silt in such a way that over time accumulation of silt occcurs behind the barriers (Webstor and Wilson, 1975). Contour strip cropping of close growing crops with clean tilled or fallow crops may reduce the erosion as much as 90 per cent (Highfill and Kimberlin, 1977).

According to Webstor and Wilson (1975) vegetative barriers are not fully effective, because gaps develop in the vegetation and allow the passage of run-off, causing gullying. They also tend to spread indiscriminately, thus necessiating labour to check them. Highfill and Kimberlin (1977) suggest to convert some crop lands to pasture or woodlands intermittantly for controlling erosion. But this may not be possible under present ownership of lands.

Tall grasses like Vetiveria zizanioides, Cympopogon citratus etc. were commonly used for the purpose of vegetative barriers (Webstor and Wilson, 1975).

8.7. Role of trees in soil conservation

Agroforestry can be defined as an approach to integrated land use involving the deliberate mixture or retention of trees or other woody perennials as part of the crop or animal production enterprises (Nair, 1984).

The taungya system of cultivation originated in Burma (Blanford, 1958) seems to be the fore-runner to agroforestry. King (1978) devided agroforestry into Agri-Silviculture, Agri-Silvipastoral, Multipurpose forest tree production systems.

According to Singh (1988) agroforestry is a sustainable land management system to optimize the resources of grain, forage, timber, animal products on the one hand and to conserve the soil, its nutrients, improve environments and rural prosperity on the other hand.

Considering the interdependency of 'erosion control' and 'maintenance of fertility', soil conservation involves both control of erosion as well as maintenance of productivity. Agroforestry can only be a practical and viable suggestion to have soil conservation in this wider sense. In the tropics, there is often considerable loss of nutrients through erosion and leaching as well as loss sustained by crop removal. In such instances if a system can be devised, which will minimize erosion through the judicious selection of trees, which tap nutrients, that are not normally available to the shallow rooting agricultural crops, that system will increase the level of fertility and will replace the nutrients taken out by the annual agricultural crops (Singh, 1988). Current interests, investments and research efforts in agroforestry are based on the expectation that the net financial return will be higher per unit of land, than from either forestry or agriculture alone.

Retention of trees or other woody perennials as a part of crop production enterprises, offers a multistorey canopy structure which serves as an effective mechanism for cushioning raindrop impact (Nair, 1984). The different strata of the canopy progressively reduce the force of rain, thereby reducing the erosivity. Increased crop canopy is hence associated with lesser run-off and soil loss (Megahan, 1978 and Lang and Mallett, 1984).

Presence of trees in a landscape affects its hydrological characteristics. Studies conducted by Pereia (1973) on the taungya in Kenya have demonstrated the favourable influence of trees on the hydrological characters and water balance of the area. Presence of trees on eroded slopes reduced run-off drastically and soil erosion was brought down from 15000 to 3000 m^3 per Km^2 over a period of 10 years (Xiaoliang, 1977).

In several states of India, eucalyptus have been planted by the farmers on field bunds in rows along water channels (Mathur et al., 1984). As a fast growing tree species with light crown, eucalyptus found its place in agroforestry system of land management (Gupta, 1986). Other commonly used species for agroforestry practices are Acacia, Casuarina, Prosopis etc.

Several researchers report the success of cultivation of various crops including grasses and legumes under eucalyptus (Pant, 1980 and Ramachandran, 1981). Suppression of undergrowth due to allelopathic effects is also reported (Rao and Reddy, 1984; Vandana Shiva and Bandopadhyay, 1985 and Prasad et al., 1985).

In case of highly eroded soils Dhruvanarayana and Rambabu (1984) reported erosion control accompanied by a benefit cost ratio upto 4.0 with a monoculture of eucalyptus alone. Sud et al. (1986) observed reduced run-off and sediment loss in a mixture of eucalyptus bhabbar grass. Agroforestry system with _Acacia mearnsii_ also showed soil conserving function.

Vandana Shiva and Bandopadhyay (1985) argue that eucalyptus hybrid is shallow rooted with low water use efficiency and hence it has no effect in soil conservation. Gopinathan (1986) obtained a net income of Rs.10.12 thousand per ha produced by eucalyptus + grass combined with complete control of soil erosion during the second year of cultivation. According to him when acceptability, profitability and sustainability are taken into account, eucalyptus intercropped cassava along with 10 per cent grass strips seems to be a better system.

More research efforts are needed to generate situation specific agroforestry measures of soil and water conservation involving a variety of crop combinations acceptable to the farmers.

Materials and Methods

MATERIALS AND METHODS

An experiment was conducted under a two year old eucalyptus plantation at the Instructional Farm, Vellanikkara with the major objective of identifying viable agroforestry systems that minimize run-off and soil loss from a steep taungya land.

1. Materials

1.1. Experimental site

The field was situated at 10° 32' N latitude and 76° 10' E longitude with an altitude of 22.25 m having a slope of 25 per cent towards north.

1.2. Climate

The area enjoyed a humid tropical climate. Monthly average values of important meteorological parameters observed during the period of investigation are presented in Fig. 2 and Appendix I.

1.3. Soil characteristics

The soil of the experimental area was shallow, well drained, moderately acidic oxisol with a sandy clay loam surface texture.

1.4. Season

The experiment was started in the first week of June 1987 and continued upto the last week of May 1988.

1.5. Crops

The following were the various crop components of the trial.

1.5.1. Eucalyptus

A hybrid species, <u>Eucalyptus</u> <u>teriticornis</u> planted at a spacing of 2 m x 2 m was the tree component. The trees were 2 years old.

1.5.2. Cassava

A variety called 'M_4' having good coocking quality was used. Setts were planted on mounds formed in a triangular way at a spacing of 0.75 m x 0.75 m.

1.5.3. Pineapple

Variety 'Kew' was used. It was intercropped with eucalyptus in trench method of planting with a spacing of 70 cm between rows and 30 cm between plants within a row. Plants were one year old.

1.5.4. Grass

A drought tolerent spreading type perennial grass Congo signal (*Brachiaria ruziziensis*) was planted.

1.5.5. Cowpea

A dual purpose variety 'Kanakamani' was used. Seeds were broadcasted at the rate of 35 kg ha^{-1} in the entire plot at the time of planting cassava.

2. Methods

2.1. Lay out of the experiment

Design	:	7 x 3 RBD
Plot size	:	24 m x 4 m

Lay out plan is given in Fig. 1. The plots were arranged lengthwise along the slope facing north.

2.2. Treatments

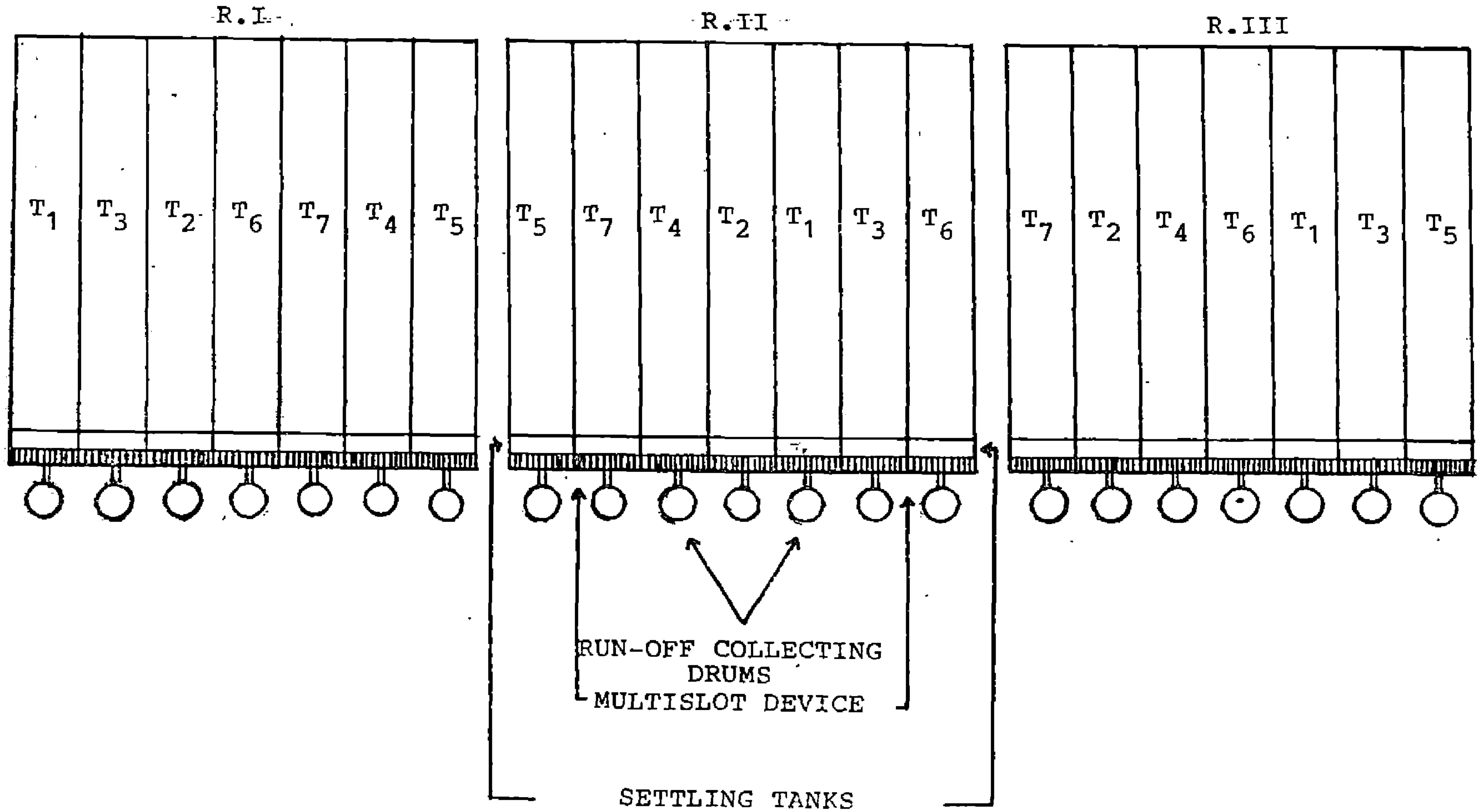
T_1 Eucalyptus alone

T_2 Eucalyptus + cassava on mounds

T_3 Eucalyptus + cassava on mounds + cowpea live mulch

T_4 Eucalyptus + cassava on mounds + barrier strips of Congo signal grass (4 strips of 1 m width at 5 m interval)

FIG. 1 LAYOUT OF THE EXPERIMENT



T_5 Eucalyptus + cassava on mounds + barrier strips of pineapple (4 strips of 1 m width at 5 m interval)

T_6 Eucalyptus + pineapple in furrows across the slope at 2 m interval

T_7 Cultivated bare fallow plot

2.3. Run-off collection

A run-off collection device specifically designed for this purpose (Gopinathan, 1986) was made use of for collecting the run-off. Brick masonry tank was provided at the bottom end of each plot so as to cover its effective width. The tank of size 3.4 m x 0.75 m x 0.35 m served as the settling tank. A multi-slot device with 47 slots of size 2.5 cm x 10 cm each was fixed at 0.35 m height on the outer edge of the settling tank exactly on the horizontal plane so as to divide the run-off into 47 equal parts.

A plastic net was fixed vertically inside the tank 15 cm ahead of the multi-slot device to filter the floating debris. A polythene delivery tube of 1.25 m length and 4 cm diameter attached to the device was connected to a run-off receiving drum of radius 28.15 cm. The drum was covered with G.I. sheet to avoid direct rain.

2.4. Run-off estimation

Run-off was estimated each day at 8.30 AM as follows.

The height of the water column in the run-off collection tank was measured and the total volume of run-off and settled sediment load was calculated. Volume of settled sediments was also determined using mass-density relationship. The actual volume of run-off in each tank was found out by deducting the sediment volume from the total volume.

The quantity of run-off overflown from the tank was calculated by multiplying the volume of water collected in the drum with the number of slots viz. 47. Total run-off from each plot was then obtained by adding this to the volume of run-off collected in the corresponding tank.

Corrections were made to the total volume of run-off for evaporatory losses as well as direct addition of rainfall in the tank.

2.5. Estimation of soil loss

2.5.1. Settled sediments

The water in the tank was slowly and carefully drained through the outlet provided at the lower end of the tank. Then the soil collected in the tank was thoroughly stirred and a representative sample of 500 g was drawn for moisture determination as well as for chemical characterisation. Wet weight of the whole eroded soil in the tank was noted and the corresponding dry weight was worked out.

2.5.2. Suspended sediments

From each collection tank a sample of 250 ml of run-off was collected in plastic bottles, following integrated sampling technique

A sample of 250 ml was drawn from the collection drum also by stirring the water thoroughly with a ladder. These samples were filtered, the sediments seperated and dried to constant weight. It was then multiplied by the corresponding volume of run-off and added to get the total suspended sediments.

2.5.3. Total soil loss

Sum of settled and suspended sediments constituted the total soil loss of each treatment and was expressed in t ha^{-1}.

2.6. Sampling for analysis

About 250 ml of run-off drawn both from the settling tank and drum on each day was preserved by adding a few drops of toluene. These were pooled together and representative monthly samples were taken for analysis.

Roughly 250 g of representative sample of settled sediments on each day was drawn, dried and pooled together month-wise and utilised for various analysis.

2.7. Rainfall characteristics

An automatic raingauge installed at the experimental area sufficiently away from crop canopy hindrances provided the daily rainfall data. This was used for deriving the following rainfall characteristics.

1. Total rainfall (mm)
2. Maximum rainfall intensities for 15 and 30 minutes interval, (cm hr^{-1})
3. Total kinetic energy of rain
4. EI_{30} index
5. EI_{15} index

The daily depth of rainfall was also checked using an ordinary raingauge installed nearby.

2.8. Manuring

All crops except eucalyptus were manured as shown below.

Cassava	:	Urea	110 kg ha^{-1}
		Super phosphate	312 kg ha^{-1}
		M.O.P.	83 kg ha^{-1}
Pineapple	:	Urea	177 kg ha^{-1}
		M.O.P.	133 kg ha^{-1}
Grass	:	Urea	333 kg ha^{-1}
		Super phosphate	312 kg ha^{-1}
		M.O.P.	83 kg ha^{-1}

2.9. Weeding and interculturing

In all plots except T_1, weeding was carried out. T_1 was kept undisturbed. In T_3 weed growth was suppressed by cowpea and a slight weeding was only needed. Hand weeding was practiced in all the treatments. Cassava required earthing up in all plots during August-September. Grass and pineapple strips were lightly digged after manuring.

2.10. Harvesting

Harvesting of cowpea was over by the end of August. Cassava was harvested during the last week of March.

grass was cut at monthly intervals. Pineapple was harvested from the first week of January and continued till the third week.

2.11. Biometric observations

2.11.1. Eucalyptus

Five plants were selected at random from each plot and the following observations were recorded at quarterly interval.

(a) Plant height (m)

As the trees were tall, direct measurement of height was difficult. Hence the plant height was recorded using Christen's Hypsometer (Chaturvedi and Khanna, 1982).

(b) Collar girth (cm) at 10 cm above the ground level.

(c) Girth at Breast Height Over Bark (GBHOB) at 1.37 m above the ground level (cm).

(d) Volume (m^3)

Total wood volume in each treatment was determined using the formula.

Volume = $-0.001 + 0.3114\ D^2H$ (Chaturvedi, 1973)

where D = Diameter (m)

H = Height (m)

2.11.2. Cassava

Total tuber yield (kg ha^{-1}) from each treatment recorded on harvest.

2.11.3. Pineapple

Total fruit yield (kg ha^{-1}) from each treatment was recorded.

2.11.4. Grass and cowpea

Yield (kg ha^{-1}) obtained from each plot were recorded.

2.12. Determination of rainfall acceptance

Rainfall acceptance is the measure of the water absorptive capacity of a treatment and is determined by the equation,

$$\frac{\text{Total rainfall - Total run-off}}{\text{Total rainfall}} \times 100$$

For this run-off occured in each treatment during the whole experimental period was taken into account.

2.13. Chemical analysis

The total N, P and K of eroded soils and run-off were determined by standard methods. Nitrogen contents were determined by microkjeldahl's method. Total phosphorus was determined colorimetrically by yellow color method using 'Spectronic-20' spectrophotometer. Potassium was estimated using flame photometer.

2.14. Statistical analysis

The data obtained were subjected to statistical analysis by the analysis of varience technique suggested by Das and Giri (1979) and Montgomery (1984).

Results & Discussion

RESULTS AND DISCUSSION

1. Weather data

The details of important weather parameters during the experimental period are provided in Fig. 2 and Appendix I.

The mean maximum temperature varied between 29.6°C (August) to 36.1°C (May) with a highest maximum of 38.0°C (March & April). With regard to mean minimum temperature the value ranged from 22.0°C (January) to 24.7°C (May) with a lowest minimum of 19.5°C (November). The month of August was the most humid recording an average relative humidity of 87 per cent. January and February were very dry with relative humidity of 56 per cent. Southwest monsoon was started in May and reached its peak in June, with a monthly total of 637 mm rainfall. The northeast monsoon started in September with highest monthly value (278 mm) in October. The total rainfall received during the whole period of experiment was 2060 mm, out of which 64 per cent was contributed by the southwest monsoon and 36 per cent by the northeast monsoon.

The run-off and erosion recorded by different treatments were influenced by the rainfall characteristics such as amount, intensity, kinetic energy erosivity

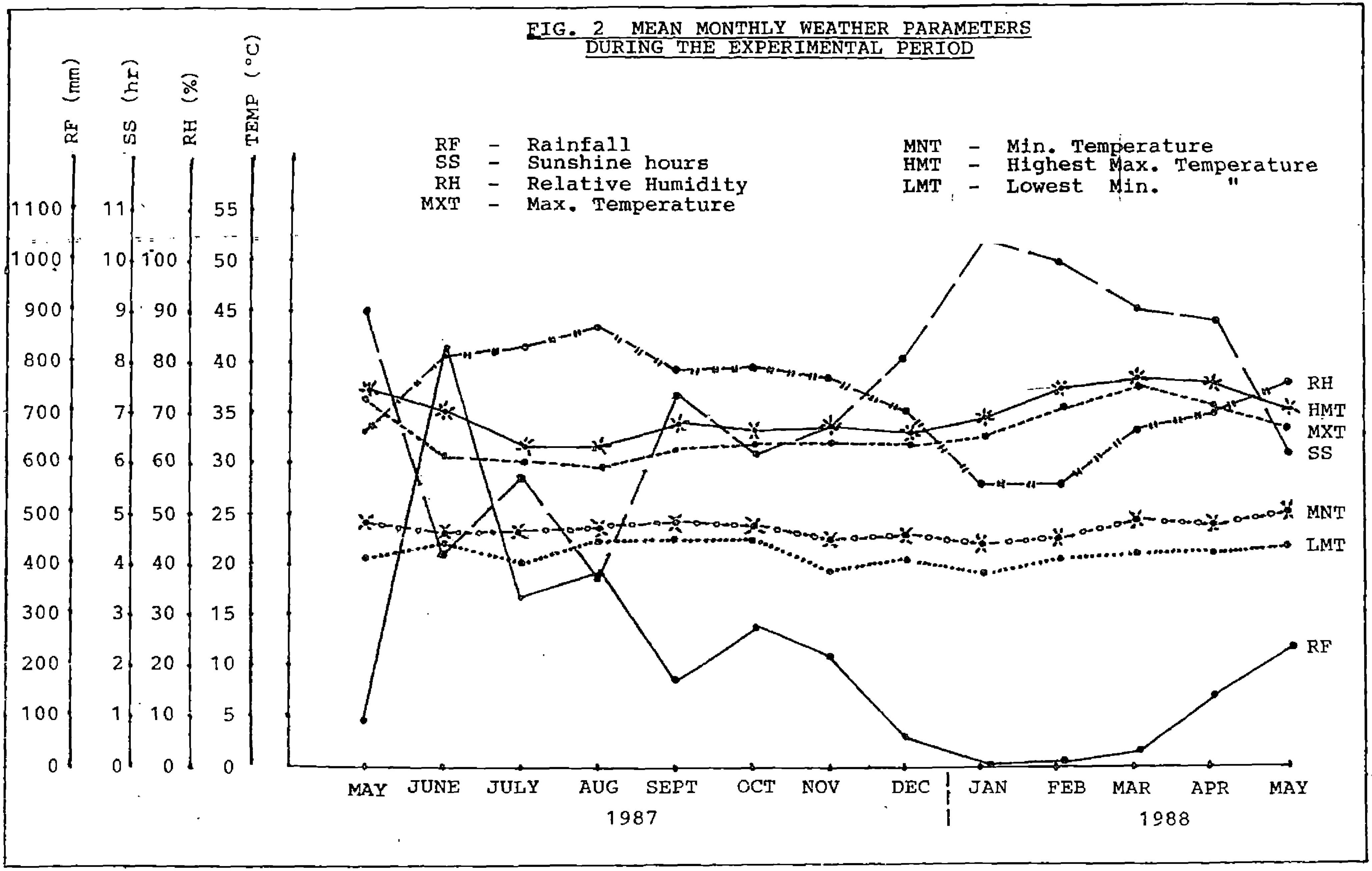


FIG. 2 MEAN MONTHLY WEATHER PARAMETERS
DURING THE EXPERIMENTAL PERIOD
RF - Rainfall
SS - Sunshine hours
RH - Relative Humidity
MXT - Max. Temperature
MNT - Min. Temperature
HMT - Highest Max. Temperature
LMT - Lowest Min. "
RF (mm)
SS (hr)
RH (%)
TEMP (°C)
1100 1000 900 800 700 600 500 400 300 200 100 0
11 10 9 8 7 6 5 4 3 2 1 0
100 90 80 70 60 50 40 30 20 10 0
55 50 45 40 35 30 25 20 15 10 5 0
MAY JUNE JULY AUG SEPT OCT NOV DEC JAN FEB MAR APR MAY
1987
1988
RH
HMT
MXT
SS
MNT
LMT
RF

indices etc. A brief description about the behaviour of these characters during the experimental period is given below.

2. Rainfall analysis

2.1. Rainfall amount, duration and events

Table 1, Fig. 3 and Appendix II furnish the details of amount, duration and events of daily rainfall registered during the period of experimentation.

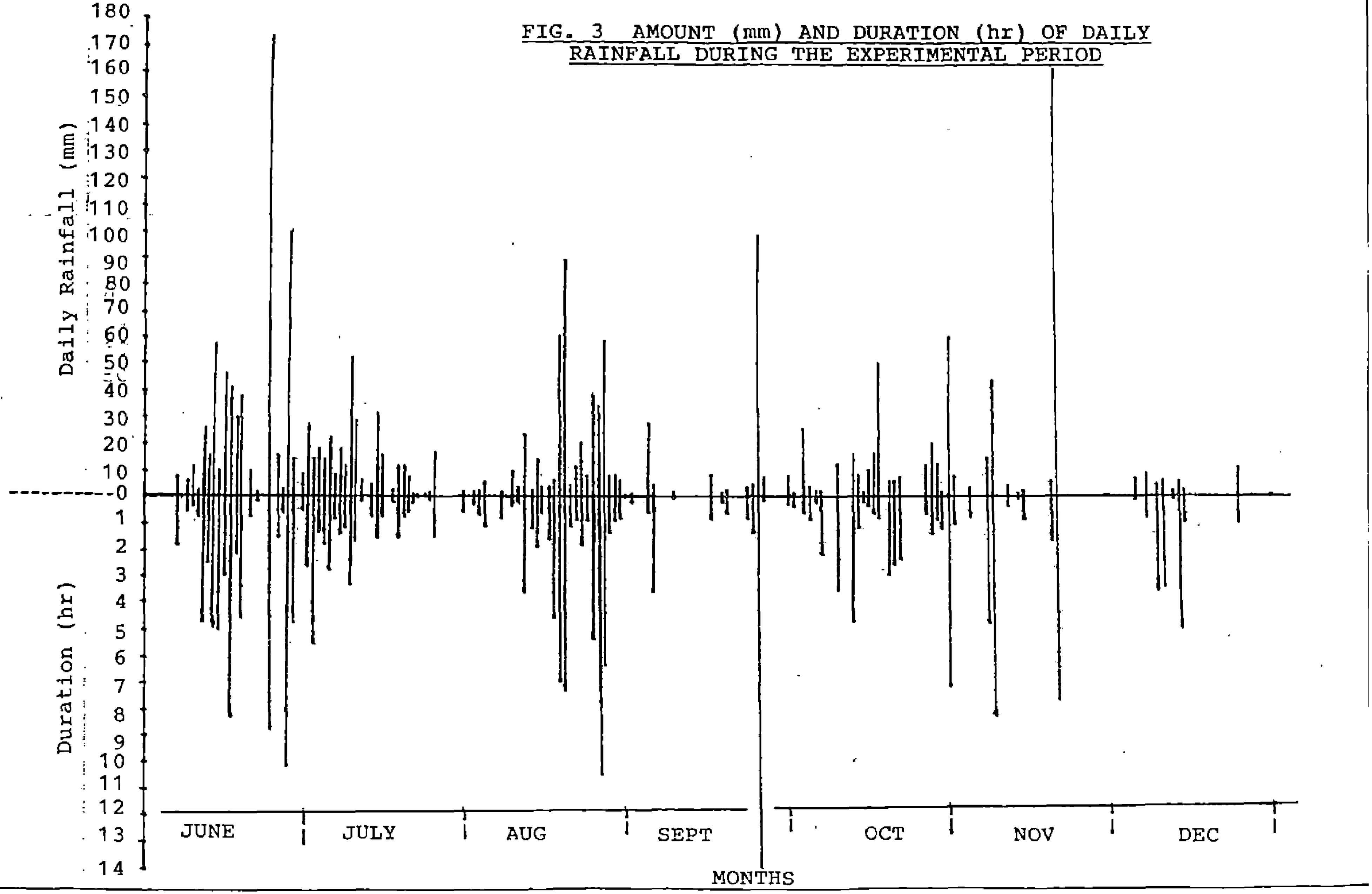
There were a total of 117 rainy days with 444 events contributing a total downpour of 2060 mm throughout the experimental period.

Among the months, June recorded the highest total of 637 mm of rainfall through 104 events in 20 rainy days. The highest daily rainfall of 173 mm was also recorded in June. However out of these 20 rainy days, only 12 days received rainfall of about 10 mm. The lowest monthly total of 43 mm was observed in December through 8 events in 8 rainy days. Barring a single event, none of the events exceeded 10 mm in December. As far as other months were concerned, they followed the order Aug. > July > Oct. > Nov. > Sept. with the corresponding values of 360.5, 309.0, 277.5, 267.5 and 165.5 mm respectively. With regard to

Table 1. Important rainfall characteristics during the experimental period

No.	Characteristics	Months						
		June	July	August	September	October	November	December
1	No. of rainy days	20	24	25	11	20	9	8
2	No. of events	104	129	122	31	40	10	8
3	Depth of rainfall (mm)	637.0	309.0	360.5	165.5	277.5	267.5	43.0
4	Total duration (hr)	62.3	38.1	61.6	23.1	35.6	25.3	15.1
5	Total kinetic energy (mt ha^{-1} cm^{-1})	14488.2	8445.0	8074.0	1187.5	4405.0	2447.0	799.2
6	EI_{30}	319.21	205.00	147.24	34.31	92.10	141.39	6.91
7	EI_{15}	367.57	307.83	164.00	53.85	126.09	162.77	13.76

FIG. 3 AMOUNT (mm) AND DURATION (hr) OF DAILY RAINFALL DURING THE EXPERIMENTAL PERIOD



number of rainy days and events also, an almost similar trend was observed among the months except September and November.

2.2. Kinetic energy and erosivity

Data are furnished in Table 1 and Appendix II.

As in the case of depth of rainfall, the highest kinetic energy of 14,488 m t ha^{-1} cm^{-1} was also observed in June. The other months followed the order July > Aug. > Oct. > Nov. > Sept. > Dec. with the corresponding values of 8445, 8074, 4405, 2447, 1188 and 799 m t ha^{-1} cm^{-1} respectively. Similarly the highest values of erosivity indices like EI_{30} (319) and EI_{15} (367) were also observed in June and the lowest in December with 6.91 and 13.76 respectively. But the erosivity indices were not proportional to the total kinetic energy as evident in October. In October though the kinetic energy was 4405 m t ha^{-1} cm^{-1} the above indices were 92 (EI_{30}) and 126 (EI_{15}) respectively. But November with a total kinetic energy of 2447 m t ha^{-1} cm^{-1}, recorded substantially higher values of 141 and 162 for EI_{30} and EI_{15} respectively, as compared to October.

From the above analysis it is evident that June was the most erosive month and December, the least. Other months followed the order July > Aug. > Nov. > Oct. > Sept. With highest rainfall amount and corresponding kinetic energy in June and the lowest rainfall and kinetic energy in December, the observed erosivity variation is explainable. But erosivity cannot always be explainable in terms of rainfall amount alone. The kinetic energy is negatively influenced by the duration of downpour (Table 1) especially when there is no corresponding increase in depth of rainfall with increase in duration. This is very clear from the daily rainfall amount and corresponding kinetic energy of some of the gentle rainy days of August or September. Similarly, kinetic energy is strongly and positively correlated with too intense rainfall (Gopinathan, 1986) as evident from daily rainfall analysis of October.

The effect of treatments on various aspects which influence the soil erosion are discussed below. With treatments as main-plots and months as sub-plots, data were analysed using split-plot technique.

3. Run-off

Results are provided in Table 2 and Fig. 4.

Data showed significant difference between treatment means. Cultivated bare fallow plot (T_7) recorded the

Table 2. Month-wise run-off (mm)

Months	Treatments							Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
June	80.86	278.96	269.39	149.79	190.72	34.19	279.88	183.40
July	20.17	116.01	101.38	44.78	87.59	7.99	106.36	69.19
August	2.84	52.28	15.15	47.76	26.78	5.08	72.35	31.75
September	2.99	19.25	7.09	7.08	10.22	4.87	37.44	12.71
October	3.18	67.49	52.01	9.40	19.05	5.09	99.39	36.52
November	4.83	117.17	92.15	35.12	60.67	5.43	123.32	62.67
December	0.19	1.62	1.35	1.57	1.48	1.24	3.21	1.52
Mean	16.44	93.25	76.93	42.21	56.65	9.13	103.14	

CD for treatment means = 28.89
CD for monthly means = 14.27
CD for monthly means within same treatment = 37.76
CD for treatment means within a month = 45.30

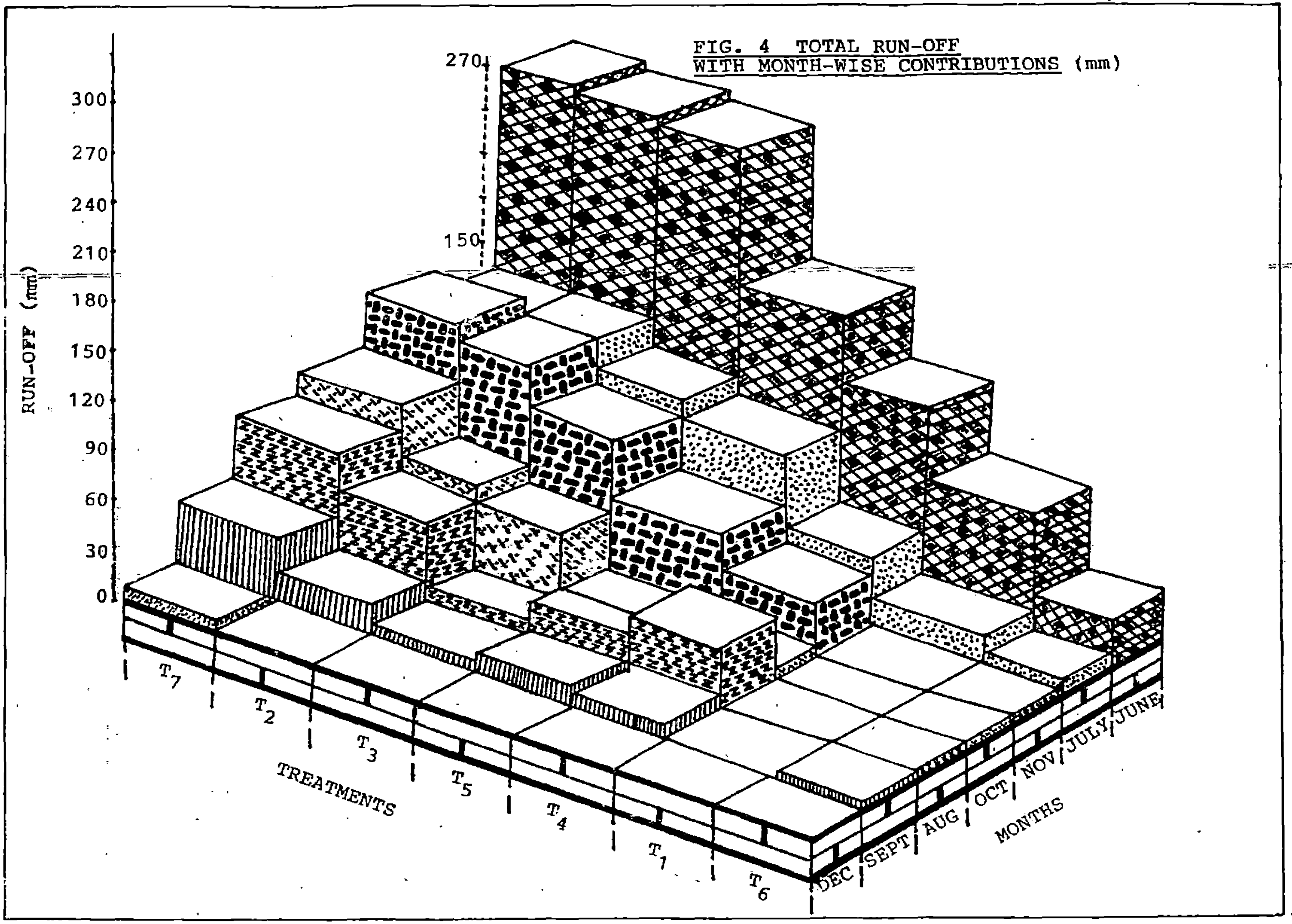


FIG. 4 TOTAL RUN-OFF
WITH MONTH-WISE CONTRIBUTIONS (mm)
RUN-OFF (mm)
300
270
240
210
180
150
120
90
60
30
0
270
150
T7
T2
T3
T5
T4
T1
T6
TREATMENTS
DEC
SEPT
AUG
OCT
NOV
JULY
JUNE
MONTHS

highest run-off of 722 mm and full pineapple cropped plot (T_6) recorded the lowest of 64 mm (Table 3). Other treatments recorded intermittent values and followed the order full cassava cropped (T_2) > cassava + cowpea (T_3) > cassava + strips of pineapple (T_5) > cassava + strips of grass (T_4) > tree alone (T_1). The treatments T_4 and T_5 as well as T_3 and T_5 did not differ significantly. The behaviour of the treatments during different months also followed the same trend as that of annual mean except in few cases like in August. In this month T_3 showed much less value than that of T_4, though in the previous month it produced significantly higher run-off over T_4.

Throughout the period, the month of June recorded the highest run-off and December the lowest. Within the treatments monthly values for all treatments except T_6, varied significantly.

In general there was a definite decreasing trend for the monthly means from June to September with a subsequent increase during October and November. December recorded the lowest run-off.

Run-off is the water that remains from precipitation after evapotranspiration and infiltration. Infiltrability of a soil reduces monotonically and reaches a constant rate over time (Hillel, 1971). On a rainy day in the rainy season, the soil will also be saturated and with each successive rainfall, the infiltration rate will be reduced, allowing more water to flow off. This process will get accelerated on bare soil consequent to the blockage of macropores by the detached soil particles. The highest quantity of run-off produced in cultivated bare fallow plot (T_7) in all the months can be attributed to the above facts. This is supported by the highest run-off in June and lowest in December, where the erosivity or the hitting power were also correspondingly the highest and lowest. Run-off variation in other months was also in agreement with the erosivity variations. Further in a thoroughly tilled soil as in T_7, the chances for the formation of rills and gullies are great which in turn might have influenced the run-off load. This is supported by the observed lowest run-off in full pineapple inter-cropped plot (T_6) where the direct hitting of rain drops over the soil surface was prevented and the possibilities of forming rills or channels were avoided by pineapple cropping in the entire plot. Here the densely developed pineapple canopy was probably responsible to rob off the energy of falling rain drops, resulting in decreasing their hitting power. Further, the fully established pineapple strips would have created a multitude of minibarriers across the flow path of run-off and thereby improved the water retention capacity of the area. This, inturn increased the opportunity time and infiltration of rain water into the soil profile, resulting in reduction of run-off to more than 90 per cent of that of the cultivated bare fallow plot.

Mound method of cassava cultivation was as deleterious as that of cultivated bare fallow as evidenced by T_2, the full cassava inter-cropped plot, which recorded almost comparable values of run-off with T_7 throughout. This suggests that the factors responsible for increased run-off in cultivated bare fallow, are equally prominent in T_2 also. The cassava canopy could not probably bring about enough protective ability in reducing the erosivity of the rainfall. Further, very severe land disturbances caused by mound method of cassava cultivation might have nullified any little amount of protective ability of trees as evidenced from T_1, the tree alone plot. Observation in T_4 and T_5 suggests that even with such deleterious practice of cultivation, run-off can be reduced to considerable extent, using, strips of grass or pineapple to an extent of 15 per cent of the land area. T_4 was better than T_5 and both were almost comparable with full pineapple cropped plot T_6, from August onwards. This is mainly because of the barrier effects of vegetative strips as already explained (Webstor and Wilson, 1975; Gopinathan, 1986).

The protective ability of ground cover has already been established by many workers (Ellison, 1944; Meyer et al., 1975; Singh, 1984 and Turner et al., 1984). The energy dissipating power of ground cover formed by the dense cowpea canopy can only be the reason attributed to the observed reduction in run-off in T_3. Even with the most deleterious mound method of cassava cultivation, there was a striking reduction of run-off in T_3 during August and September consequent to the fully developed cowpea canopy. Gopinathan et al. (1988) also established a 30 per cent reduction in run-off with cowpea live mulch under identical edapho-climatological conditions. These findings reietrate the importance of ground cover and vegetative barriers in bringing down the run-off losses in steep hill slopes where subsistance agriculture is practiced.

4. Rainfall acceptance

Data are provided in Table 3.

Table 3. Annual run-off (mm) and rainfall acceptance(%)

		Treatments						
		T_1	T_2	T_3	T_4	T_5	T_6	T_7
1	Total rainfall (mm)	2060.0	2060.0	2060.0	2060.0	2060.0	2060.0	2060.0
2	Run-off loss (mm)	115.1	652.8	538.5	295.5	396.5	63.9	721.9
3	Run-off (%)	5.59	31.69	26.14	14.34	19.25	3.10	35.04
4	Accepted rainfall (mm)	1944.9	1407.2	1521.5	1764.5	1663.5	1996.1	1338.1
5	Rainfall acceptance (%)	94.41	68.31	73.86	85.66	80.75	96.90	64.96

The highest rainfall acceptance of 97 per cent was recorded by T_6, full pineapple cropped plot followed by T_1 the tree alone treatment with 94 per cent. The least value of 65 per cent was shown by T_7 (cultivated fallow). Treatments with vegetative barrier strips, T_4 and T_5 absorbed more than 80 per cent of rainfall. Cowpea live mulched plot exhibited about 10 per cent more rainfall acceptance over the full cassava treated plot.

Rainfall acceptance is that portion of rainfall, after run-off expressed as percentage of total rainfall. It is a measure of the effectiveness of each treatment in harvesting the rainfall and infiltrating it into the soil profile. Such of those factors responsible for reducing the run-off and increasing infiltration rate are, therefore, responsible for increase in rainfall acceptance also.

5. Soil loss

5.1. Settled sediment loss

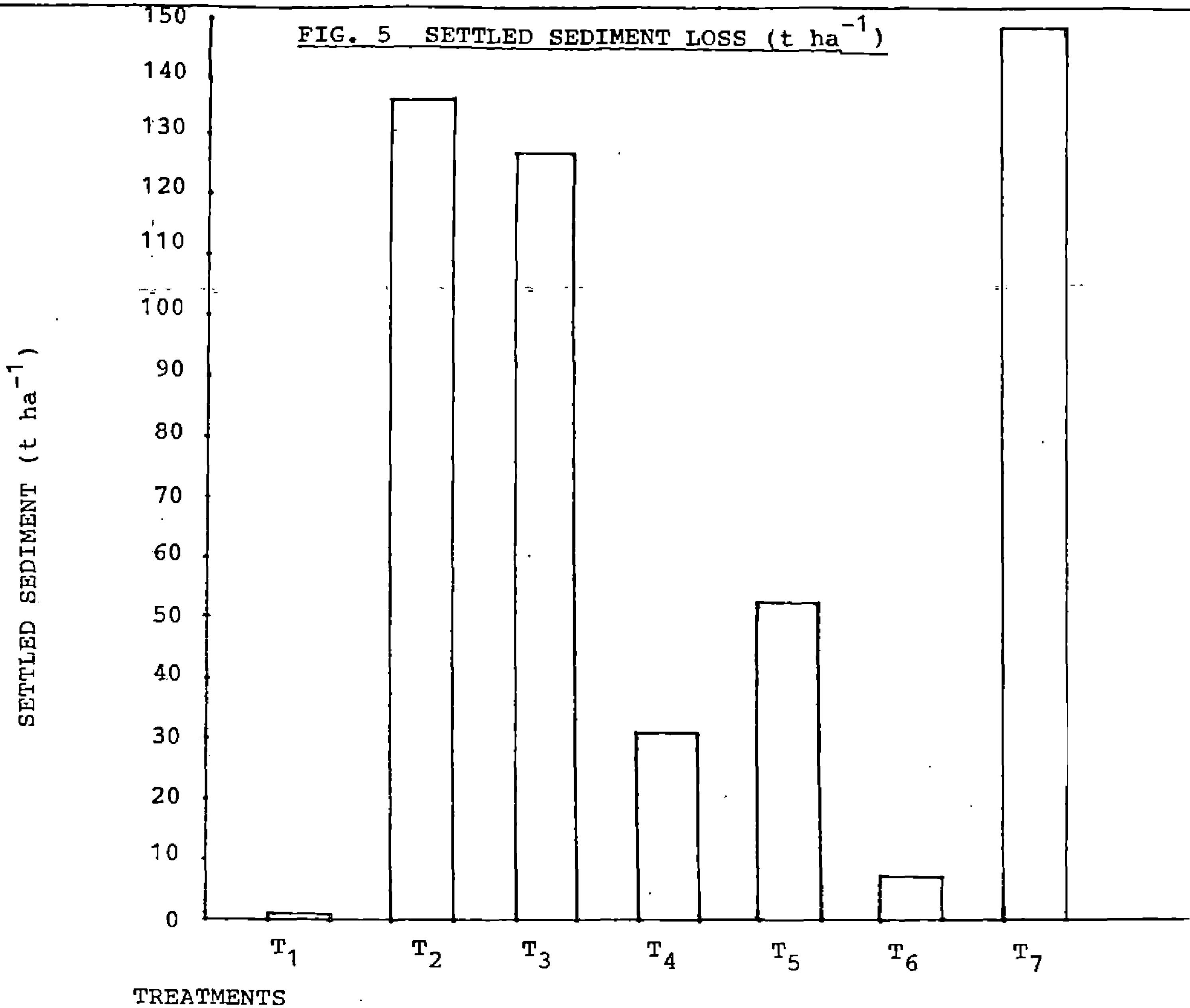
The total soil loss includes both settled as well as suspended sediments carried away by the run-off. The data on settled sediment is furnished in Table 4 and Fig. 5.

Table 4. Month-wise loss of settled sediments (t ha^{-1})

Month	Treatments							Mean
	T	T	T	T	T	T	T	
June	0.726	113.645	110.804	27.761	39.716	4.444	129.6[illegible]1	60.958
July	0.000	10.950	8.294	2.385	7.732	0.701	12.426	6.070
August	0.000	1.055	0.791	0.010	1.097	0.146	2.715	0.831
September	0.000	0.701	0.552	0.250	0.625	0.444	0.416	0.427
October	0.000	3.545	2.153	0.111	0.774	0.347	1.625	1.222
November	0.000	6.284	4.548	0.611	2.104	1.003	1.493	2.292
Mean	0.121	22.697	21.190	5.188	8.675	1.181	24.714	

CD for treatment means = 5.14 CD for monthly means within same treatment = 10.99
CD for monthly means = 4.15 CD for treatment means within same month = 11.25

FIG. 5 SETTLED SEDIMENT LOSS (t ha^{-1})



Settled sediment loss showed almost comparable trend as that of run-off. Cultivated fallow (T_7) recorded the highest value and tree alone (T_1) the lowest, very closely preceded by the full pineapple treated (T_6). The plots with full cassava treated (T_2) and cassava + cowpea live mulched (T_3) recorded comparable values with that of T_7. Cassava + grass stripped (T_4) and cassava + pineapple stripped (T_5) produced significantly lower sediment loss than that of T_7 and other cassava cropped plots. Within each month also, treatments followed a similar pattern, except during the final few months. June recorded the highest settled sediment loss which was significant over those of all the other months. In general the other months followed the order July > Nov. > Oct. > Aug. with July recording significant difference over the others except November. Within each treatment also the monthly differences were almost similar except in interstripped plots which showed some minor variations.

Soil erosion is a function of rainfall erosivity and soil erodibility (Hudson, 1977). Since erodibility is mainly an inherent character of the soil, the observed variation in settled sediment loss between treatments can be attributed to their respective influences on rainfall erosivity and sediment carrying capacity of run-off. The treatment, T_7 was subjected to direct hitting of rainfall, since it was kept fallow and there was no protective cover or crop management practices. The soil detachability of the falling raindrop and transportability of the run-off were very high which resulted in the maximum sediment loss of 148.0 t ha^{-1} (Table 6). On the contrary, T_1 recorded the lowest value of 0.7 t ha^{-1}, where two year old eucalyptus tree alone was there. Further, there was no interculturing and consequent land distrubances. The whole area was also completely covered by natural undergrowths. These favourable situations compared to as that of an afforested area helped in reducing the erosivity and flow rate of the run-off sufficient enough to scour any measurable quantity of soil.

The significantly lower value of 7 t ha^{-1} which is well below the permissible level of erosion (Requier, 1982), observed in T_6 (full pineapple cropped) is almost comparable to that of T_1 (tree alone). Here the dense pineapple canopy coupled with the protective ability of a multitude of mini-barriers of strips across the slope helped in reducing the already explained erosion processes drastically. Further the soil binding ability and infiltration accelerating characteristics of the dense root mass of pineapple (Collins, 1960) might have also contributed to the observed reduction in loss of settled sediments. Recording 136.0 t ha^{-1} of settled sediment loss, T_2 became most erosive after T_7. Here, though trees were there as in T_1, the land disturbances caused by the mound method of cassava cultivation was sufficient enough to neutralise the protective ability of the trees. Also, there was no barrier effects against the down-flowing run-off forming rills, encircling the newly formed mounds, as in T_4 and T_5. In all the barrier stripped plots, there was sufficient reduction in settled sediments irrespective of adopting mound method of cassava cultivation. Among strip cropped plots, grass strips were found better than pineapple strips in reducing sediment loss. The superiority of grass stripped plots over pineapple stripped ones, can be attributed to the lower run-off, consequent to the higher transpiratory withdrawal of dense grass canopy and the increased infiltrability along the grass strips as suggested by Hudson (1984). T_3 (cassava + cowpea) recorded a reduction in settled sediment loss throughout the period, eventhough it accommodated same number of cassava as in T_2, the worst inter-cultured treatment. This is because of the protective ability of the cowpea ground cover against soil detachment and inter-rill erosion of the soil particles.

The observed monthly variations of settled sediment was mainly in agreement with the monthly differences of important rainfall characteristics (Table 1). For example June with 637 mm, 14488 m t ha^{-1} cm^{-1}, 319, 368 respectively of rainfall, kinetic energy, EI_{30} and EI_{15}, produced the highest sediment loss in all the treatments, while September with the lowest respective values of 166, 1188, 34 and 54 for the above items, produced the lowest sediment loss among the erosive months. December produced no sediment loss due to non-erosive rains. Since strong positive linear correlations have been established for the above indices under identical conditions (Viswambaran, 1980; Gopinathan, 1986) the monthly variations observed can easily be explained in consultation with Table 1 and Appendix II.

5.2. Suspended sediment loss

Data are presented in Table 5 and Fig. 6.

The annual treatment means showed comparable trend with that of the settled sediments, except for the slightly higher value of T_2 over T_7. However T_2 and T_7 were closely

Table 5. Month-wise loss of suspended sediments (t ha^{-1})

Month	Treatments							Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
June	0.162	9.206	8.054	3.445	4.230	0.213	8.041	4.765
July	0.018	3.258	0.936	0.366	0.821	0.002	2.713	1.159
August	0.000	1.040	0.160	0.328	0.159	0.000	1.303	0.427
September	0.001	0.395	0.283	0.086	0.138	0.001	0.800	0.244
October	0.001	0.844	0.532	0.109	0.263	0.000	1.626	0.482
November	0.000	2.595	1.919	2.019	0.216	0.017	0.330	1.013
Mean	0.030	2.890	1.981	1.059	0.971	0.039	2.469	

CD for treatment means = 1.25 CD for monthly means within a treatment = 2.68
CD for monthly means = 1.01 CD for treatment means within same month = 2.74

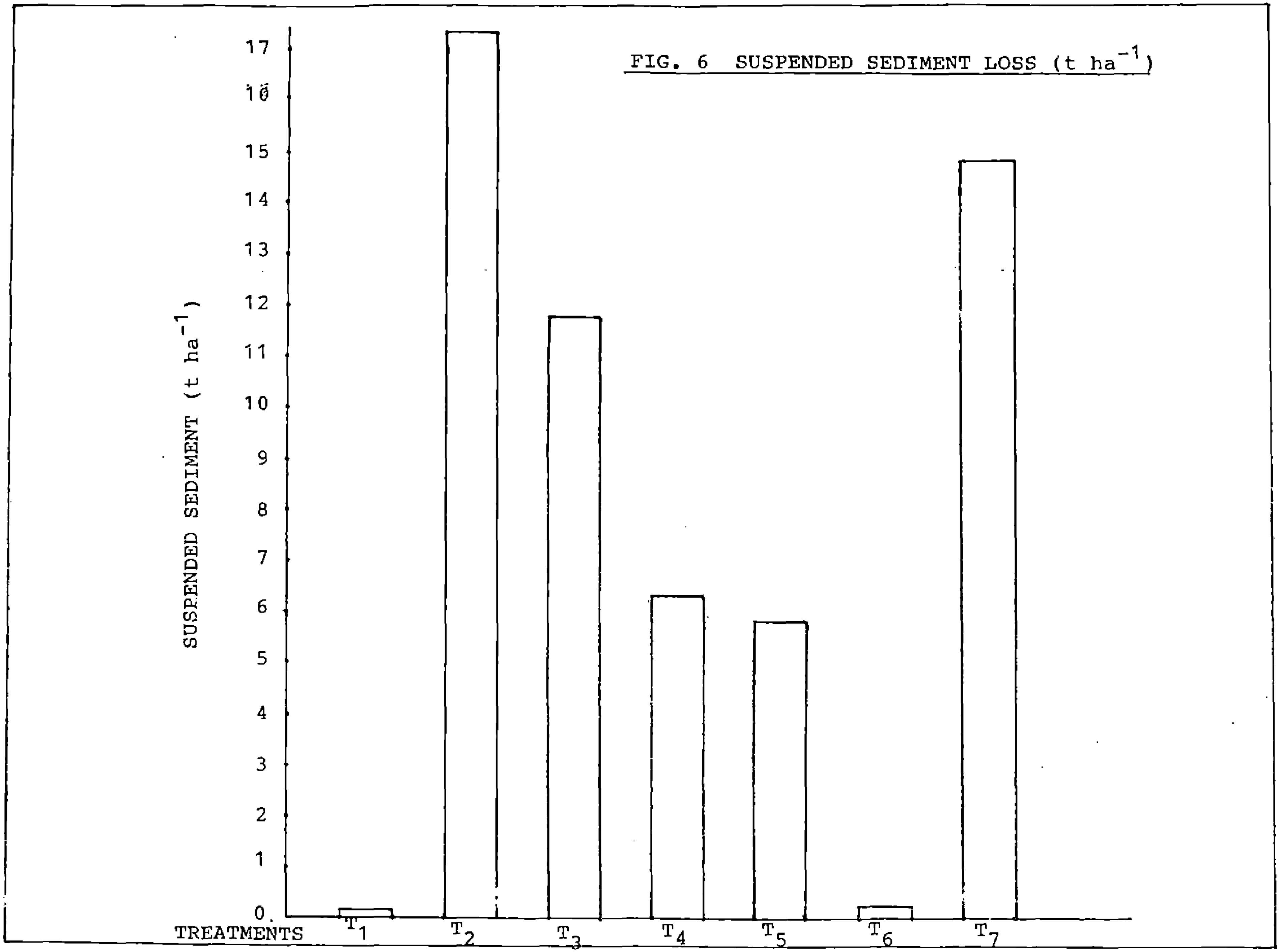


FIG. 6 SUSPENDED SEDIMENT LOSS (t ha^{-1})
SUSPENDED SEDIMENT (t ha^{-1})
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
TREATMENTS
T_1
T_2
T_3
T_4
T_5
T_6
T_7

followed by T_3. T_1 showed the lowest value preceded by T_6, T_5 and T_4 in that order. Monthly variations between treatments also followed a similar pattern except in August, September and October.

Monthly means followed the order June > Nov. > July > Oct. > Aug. > Sept. with June recording significantly higher values always. Monthly variations within each treatment followed an almost similar pattern with a few exceptions.

Suspended sediment is the dispersed soil particles, held against gravitation at the time of observation. Soil dispersement is influenced by the hitting action of the raindrops and the turbulence of the rill-flow. Total suspended sediment load in run-off is, therefore, determined by the rate of suspended soil particles and the volume of the run-off. Hence the highest quantities of suspended sediment load observed in T_2, T_7 and T_3 can be attributed to the reasons already explained for the increased run-off and bed load loss. However, a slight superiority by T_2 over T_7 requires some clarification. As T_2 is fully occupied by cassava plants, the possible high energy of the leaf drips (Noble and Morgan, 1983, Finney, 1984 and Gopinathan, 1986) might have increased the soil detachment and soil dispersion. The turbulent rill-flow quite often encircling the newly formed mounds also might have augmented this process. These probabilities are further clear from the observed reduction in suspended sediment load by more than 30 per cent in T_3 (Table 6), where there was a cowpea ground cover to check these factors. The protective mechanisms explained in previous sections hold good in understanding the reduced suspended sediment loss in T_1, T_4, T_5 and T_6.

Such of those factors described previously are responsible for the monthly variations in suspended sediment load also. Within each treatment, the monthly variations in suspended sediment are attributed to the reasons explained in section 5.1.

5.3. Total soil loss

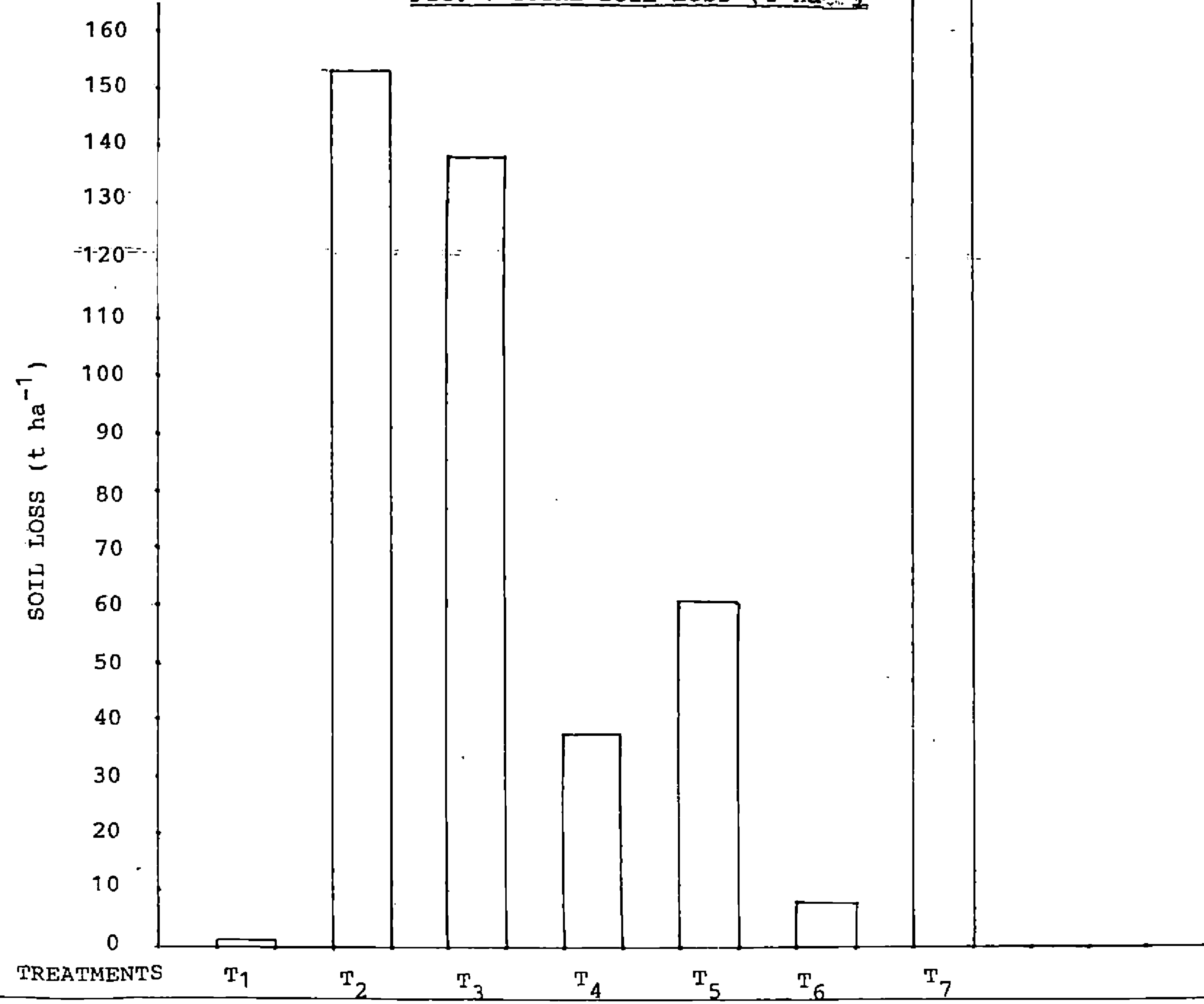
Table 6 and Fig. 7 provide the data on total soil loss.

Cultivated fallow (T_7) produced the highest soil loss of 163 t ha^{-1} and the full tree treated (T_1), the lowest of 0.9 t ha^{-1}. Other treatments followed the order $T_2 > T_3 > T_5 > T_4 > T_6$ with corresponding values of 154, 139, 58, 37 and 7 t ha^{-1} respectively.

Table 6. Annual total soil loss (t ha^{-1})

	Treatments						
	T_1	T_2	T_3	T_4	T_5	T_6	T_7
Loss of settled sediment	0.726	136.181	127.143	31.129	52.049	7.086	148.286
Loss of suspended sediment	0.182	17.338	11.884	6.354	5.827	0.234	14.814
Total soil loss	0.908	153.519	139.027	37.483	57.876	7.320	163.100

FIG. 7 TOTAL SOIL LOSS (t ha^{-1})



As total soil loss is constituted by settled as well as suspended sediments, variations in soil loss can better be understood by the combined factors responsible for the above losses. The lowest soil loss of 0.9 t ha^{-1} was observed in full tree cropped T_1. This is almost negligible when compared to the permissible level of soil loss of 10 t ha^{-1} yr^{-1} (Requier, 1982). As against this, more than 15 times higher the permissible level of soil loss observed in cassava alone intercropped plot (T_2), illustrates the interference of man through unscientific agricultural operations in accelerating soil erosion. Though afforestration is the best solution in controlling soil erosion in hill slopes as evidenced from T_1, acute pressure on available land as that in Kerala does not permit this situation to exist. Further the subsistence agriculture especially with highly erosion permitting crop like cassava can further aggrevate the situation. The results revealed that even in such a destructive treatment like T_2, a cowpea live mulch alone could reduce the soil loss by about 10 per cent. By introducing vegetative strips, the soil loss can be further reduced as observed in T_4 and T_5. Introduction, of pineapple strips over 15 per cent area could reduce the soil loss by 60 per cent, while grass strips of the same extent could reduce it by more than 75 per cent. Full pineapple intercropped, T_6 was very efficient in controlling soil loss to almost 95 per cent and in many months which was even comparable to that of the tree alone plot. These observations also emphasise that it is not the crop which is soil depleting but the crop management (Hudson, 1984). Here comes the importance of vegetative measures of soil conservation in steep hill slopes where subsistence agriculture is practiced and mechanical measures are not followed for socio economic reasons.

6. Nutrient loss

The percentage contents and total losses of major nutrients through eroded soil and run-off are discussed below. Zero values are indicative of zero erosion.

6.1. Nutrient contents in eroded so'

The total contents of nitrogen, phosphorus and potassium in eroded soil are presented in Table 7, 8 and 9 respectively.

Consultation of Table 7 revealed that eroded soils from treatments under severe soil disturbances like T_7, T_2 and T_3 recorded higher mean nitrogen contents and in other plots the values were significantly lesser. The

Table 7. Nitrogen content in eroded soil (%)

Months	Treatments							Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
June	0.038	0.141	0.130	0.139	0.124	0.125	0.148	0.121
July	0.000	0.131	0.131	0.137	0.101	0.114	0.107	0.103
August	0.000	0.138	0.133	0.133	0.970	0.099	0.100	0.100
September	0.000	0.127	0.114	0.061	0.096	0.038	0.100	0.077
October	0.000	0.061	0.087	0.054	0.034	0.030	0.085	0.050
November	0.000	0.085	0.091	0.050	0.034	0.030	0.057	0.049
Mean	0.006	0.114	0.114	0.096	0.081	0.073	0.099	

CD for treatment means = 0.0046 CD for monthly means within same treatment = 0.0096
CD for monthly means = 0.0036 CD for treatment means within same month = 0.0098

Table 8. Phosphorus content in eroded soil (%)

Months	Treatments							Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
June	0.009	0.045	0.036	0.040	0.039	0.026	0.036	0.033
July	0.000	0.041	0.036	0.033	0.031	0.021	0.033	0.028
August	0.000	0.036	0.032	0.029	0.031	0.022	0.032	0.026
September	0.000	0.033	0.030	0.015	0.010	0.015	0.030	0.019
October	0.000	0.027	0.020	0.013	0.010	0.010	0.029	0.016
November	0.000	0.017	0.015	0.010	0.010	0.007	0.018	0.011
Mean	0.001	0.033	0.028	0.023	0.022	0.017	0.029	

CD for treatment means = 0.0022 CD for monthly means within same treatment = 0.0049
CD for monthly means = 0.0018 CD for treatment means within same month = 0.0050

Table 9. Potassium content in eroded soil (%)

Months	Treatments							Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
June	0.085	0.249	0.220	0.232	0.246	0.220	0.230	0.212
July	0.000	0.240	0.203	0.226	0.240	0.206	0.224	0.191
August	0.000	0.244	0.213	0.186	0.213	0.150	0.173	0.168
September	0.000	0.240	0.215	0.206	0.191	0.100	0.166	0.159
October	0.000	0.177	0.176	0.133	0.163	0.100	0.167	0.131
November	0.000	0.057	0.176	0.120	0.130	0.050	0.171	0.100
Mean	0.014	0.201	0.201	0.184	0.197	0.137	0.188	

CD for treatment means = 0.0252 CD for monthly means within same treatment = 0.0650
CD for monthly means = 0.0245 CD for treatment means within same month = 0.0646

lowest mean value of 0.006 per cent was observed in T_1, while, T_2 and T_3 recorded a value of 0.114 per cent, the highest. There was a definite decrease in N content from the initial months to the final months in all the treatments. The highest content of N was shown by T_7 during June and the lowest by T_6 during November. In general there was no significant difference between values of different treatments within each month. Monthly values varied in between 0.049 to 0.121 per cent.

Phosphorus content in eroded soil (Table 8) also showed an exactly similar trend between treatments and months. The highest mean value of 0.033 per cent was recorded by T_2 closely followed by T_7 with a value of 0.029. T_1 recorded lowest mean value of 0.001. Monthly values varied in between 0.011 to 0.033.

Table 9 provides potassium contents of eroded soil. Here also the annual and monthly means of treatments showed similar pattern as that of other nutrients. Treatments T_2 and T_3 recorded the highest value of 0.201 per cent with the lowest value of 0.014 in T_1. T_2, T_3, T_7 and T_5 were statistically on par with each other. Among the intercultivated plots, T_6 recorded the lowest value of 0.137 preceded by T_4 with 0.184. The monthly means were also reducing gradually towards the fag end of the experiment in all the treatments and were ranged between 0.212 to 0.100.

Initially, the eroded soil from all treatments showed higher contents of N, P and K. However subsequently over the months, the nutrient contents got tapered to significantly lower values in all the treatments. For instance, while June recorded 0.121 per cent N, November the least erosive month, registered 0.049 per cent, a reduction to about 40 per cent over the former. This initial high contents of nutrients can be attributed to the possibly high clay and silt fractions in the eroded soils of plots receiving very severe soil disturbances, as observed by Gopinathan (1986) under the same edapho-climatological conditions. Over the months, the minor particles of the eroded soil would come down, consequent to stabilisation and lack of soil disturbances and hence recorded lower values of nutrients. This is further clear from the substantially lower contents of nutrients in plots which registered lesser soil losses, consequent to better conservation techniques as observed in T_6. Reduced availability of nutrients consequent to continued crop uptake and erosion may also probably responsible for the observed reduction in nutrient contents over the months.

6.2. Nutrient contents in run-off

Tables 10, 11 and 12 provide concentrations of N, P and K respectively in run-off at monthly intervals.

Nutrient contents in run-off also showed a similar trend as that of eroded soil. The highest mean N content of 2.01 ppm was observed in T_3 followed by 1.81 in T_2. The lowest value of 1.21 was recorded in T_7 closely preceded by T_1 with a value of 1.26. The highest monthly mean of 2.38 ppm recorded in June was significantly higher than those of all the other months and this tapered to a value of 0.96 in November. Within each treatment also the values were coming down gradually from June to November.

The P content in run-off was highest (0.24 ppm) in T_2 and lowest (0.08 ppm) in T_1. All the cassava cultivated plots registered significantly higher values than the others. The monthly mean varied from 0.05 ppm in November to 0.31 ppm in June and differences were significant among the months.

Table 10. Nitrogen content in run-off (ppm)

Months	Treatments							Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
June	1.637	2.663	2.597	2.563	2.613	2.483	2.100	2.379
July	1.630	2.230	2.370	2.270	2.237	2.097	1.208	2.006
August	1.437	2.323	2.473	2.227	2.167	2.043	1.010	1.954
September	0.987	1.650	2.010	1.500	1.500	1.037	0.997	1.383
October	0.937	1.000	1.357	1.060	1.240	0.866	0.937	1.056
November	0.900	0.993	1.243	1.073	0.733	0.800	0.996	0.962
Mean	1.255	1.809	2.008	1.782	1.748	1.554	1.208	

CD for treatment means = 0.2048

CD for monthly means = 0.1631

CD for monthly means within same treatment = 0.4315

CD for treatment means within same month = 0.4430

Table 11. Phosphorus content in run-off (ppm)

Months	Treatments							Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
June	0.198	0.400	0.360	0.363	0.346	0.283	0.250	0.314
July	0.160	0.323	0.300	0.270	0.316	0.200	0.200	0.252
August	0.100	0.302	0.280	0.263	0.280	0.200	0.180	0.229
September	0.000	0.170	0.183	0.150	0.130	0.090	0.100	0.117
October	0.000	0.130	0.150	0.100	0.110	0.000	0.080	0.081
November	0.000	0.090	0.100	0.066	0.060	0.000	0.000	0.045
Mean	0.076	0.235	0.228	0.202	0.207	0.128	0.135	

CD for treatment means = 0.0292 CD for monthly means within same treatment = 0.0653
CD for monthly means = 0.0247 CD for treatment means within same month = 0.0663

Table 12. Potassium content in run-off (ppm)

Months	Treatments							Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	
June	2.397	3.770	3.023	3.010	2.960	2.333	1.980	2.782
July	2.133	2.763	3.030	2.330	2.337	2.150	1.336	2.297
August	1.240	2.039	1.900	1.950	2.000	1.370	1.070	1.652
September	0.963	1.463	1.440	1.793	1.727	1.037	0.937	1.337
October	0.703	0.990	1.003	0.940	0.900	0.750	0.660	0.849
November	0.233	0.990	0.853	0.650	0.900	0.617	0.450	0.670
Mean	1.278	2.002	1.875	1.778	1.804	1.376	1.072	

CD for treatment means = 0.1180
CD for monthly means = 0.1064
CD for monthly means within same treatment = 0.2814
CD for treatment means within same month = 0.2829

Regarding K content, treatment means varied between 2.00 ppm in T_2 to 1.07 ppm in T_7 and the variation was significant. The cassava cultivated plots recorded higher values over others. Monthly mean differences were also significant and as in other nutrients, June recorded maximum value and November the minimum. There was a gradual decrease from June to November in all the treatments.

The relative mobility and leachability of various ions are mainly responsible for this variations of their contents in run-off. In general the contents of nutrients in the run-off followed the order $K > N > P$. This can be explained as follows. The predominantly Kaolinitic soils of the experimental area along with the monovalent nature of K increased its leachability in erosion cycle and, therefore, recorded highest content than the other two. Almost closely comparable values of N with that of K is possibly due to the greater mobility of NO_3^- ion which stands as the major and weakly held form of soil N. The low contents of dissolved P were probably related to the low levels of native available P and high P fixation capacity of 1:1 clay minerals of the experimental site.

Among the treatments, all the intercropped ones except T_6 showed higher contents of dissolved N, P and K, irrespective of the possibly higher crop removal as compared to T_1 and T_7. This is because of the severe soil loss and consequent washing down of the readily soluble nutrients added mainly through fertilizers. This can be further evidenced from the lower dissolved nutrient contents in T_7 and T_6, where, separate reasons might have played. For instance, T_7 was severely tilled and disturbed and, therefore, experienced greater soil loss. It showed substantially reduced contents of dissolved nutrients over T_2 and T_3 because of non-fertilization. Similarly though T_6 received the highest quantities of N and K fertilizers (80 kg each) as there was no appreciable run-off loss, it recorded lower contents. These observations support that both conservation measures and vegetations are essential in controlling non-point source of fertilizer pollution from farm fields

The observed reduction in dissolved contents of all nutrients from initial to final erosive months can be attributed to the reduced nutrient content and increased crop removal over the months

6.3. Total nutrient loss

The total nutrient loss constitutes the amount lost through run-off and eroded soil. Table 13 and Fig. 8, 9, 10 provide the data on total nutrient loss.

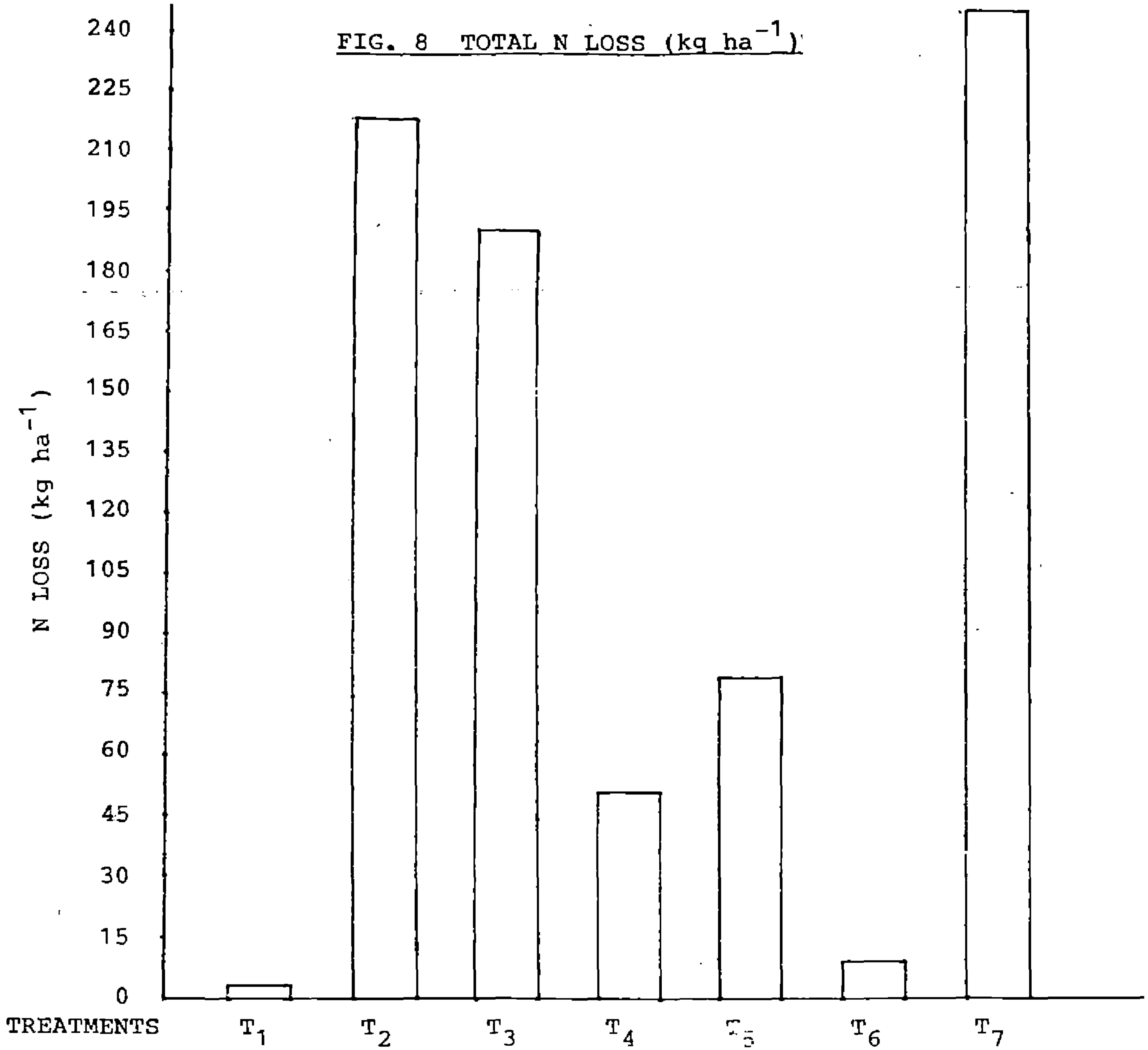
The highest N and K losses were observed in cultivated fallow and P in full cassava cropped plot. T_7 had lost 242, 60 and 384 kg ha^{-1} of N, P and K respectively. These values were 220, 67 and 377 kg, respectively, for T_2. T_3 closely followed T_2 in nutrient loss. The lowest nutrient loss was observed in T_1 with 2.14, 0.27 and 3.22 kg N, P and K each. Among the intercropped treatments T_6 recorded the lowest values and were to the extent of 8.69, 1.74 and 14.52 kg N, P and K, respectively.

The total quantity of nutrients eroded is determined by both their contents and the magnitude of the transporting media, ie. soil and water. Hence the factors responsible for the variation in quantities of run-off and soil loss and also for the variation in nutrient contents in these two media were found to be responsible for the observed differences in loss of total quantities of nutrients also. The treatments which

Table 13. Total nutrient loss (kg ha^{-1})

Nutrients	Treatments						
	T_1	T_2	T_3	T_4	T_5	T_6	T7
N	2.136	219.766	188.487	57.134	77.207	8.688	242.142
P	0.265	66.802	49.688	15.093	22.386	1.737	59.667
K	3.215	377.494	311.721	91.695	151.151	14.523	383.815

FIG. 8 TOTAL N LOSS (kg ha^{-1})



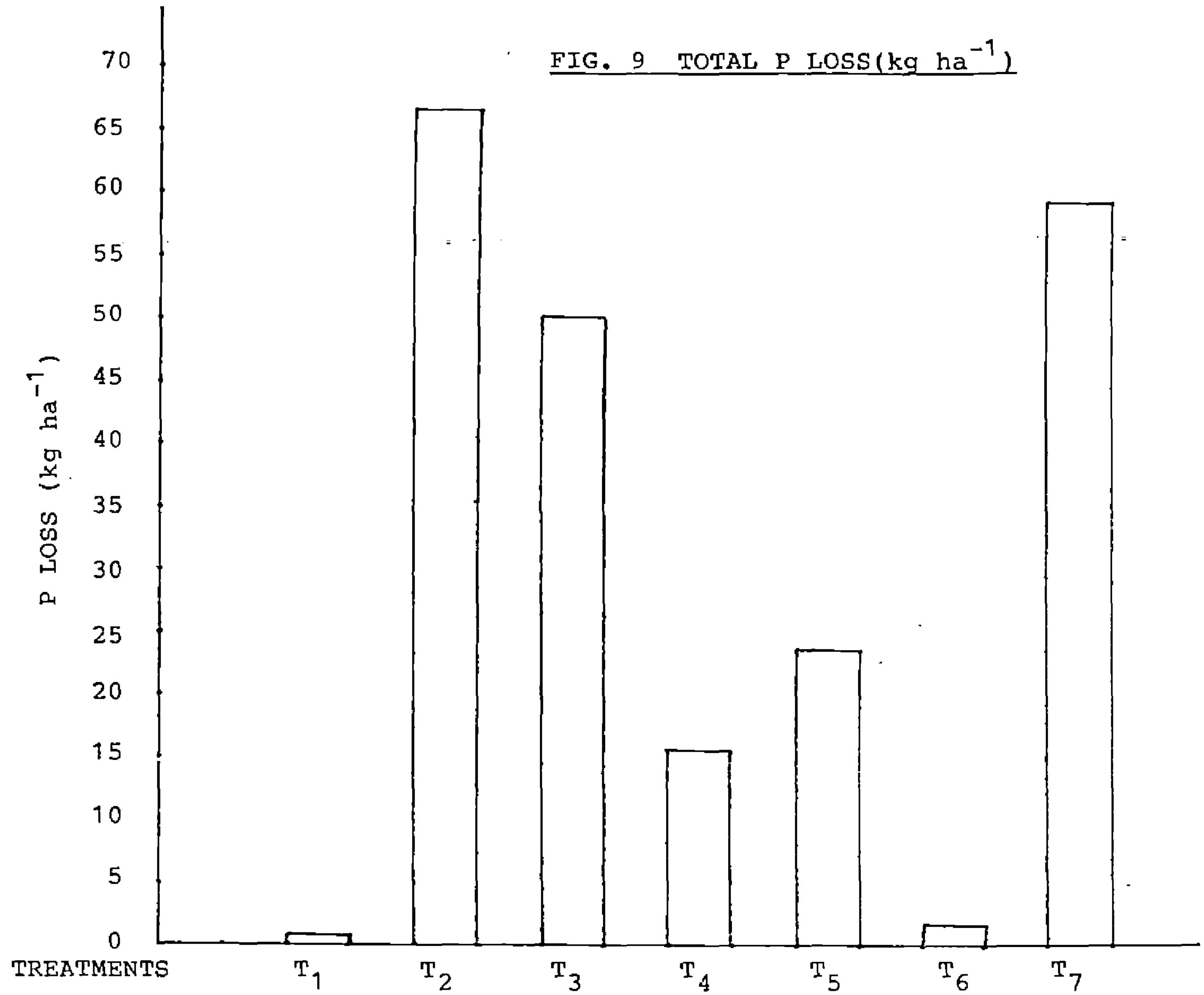
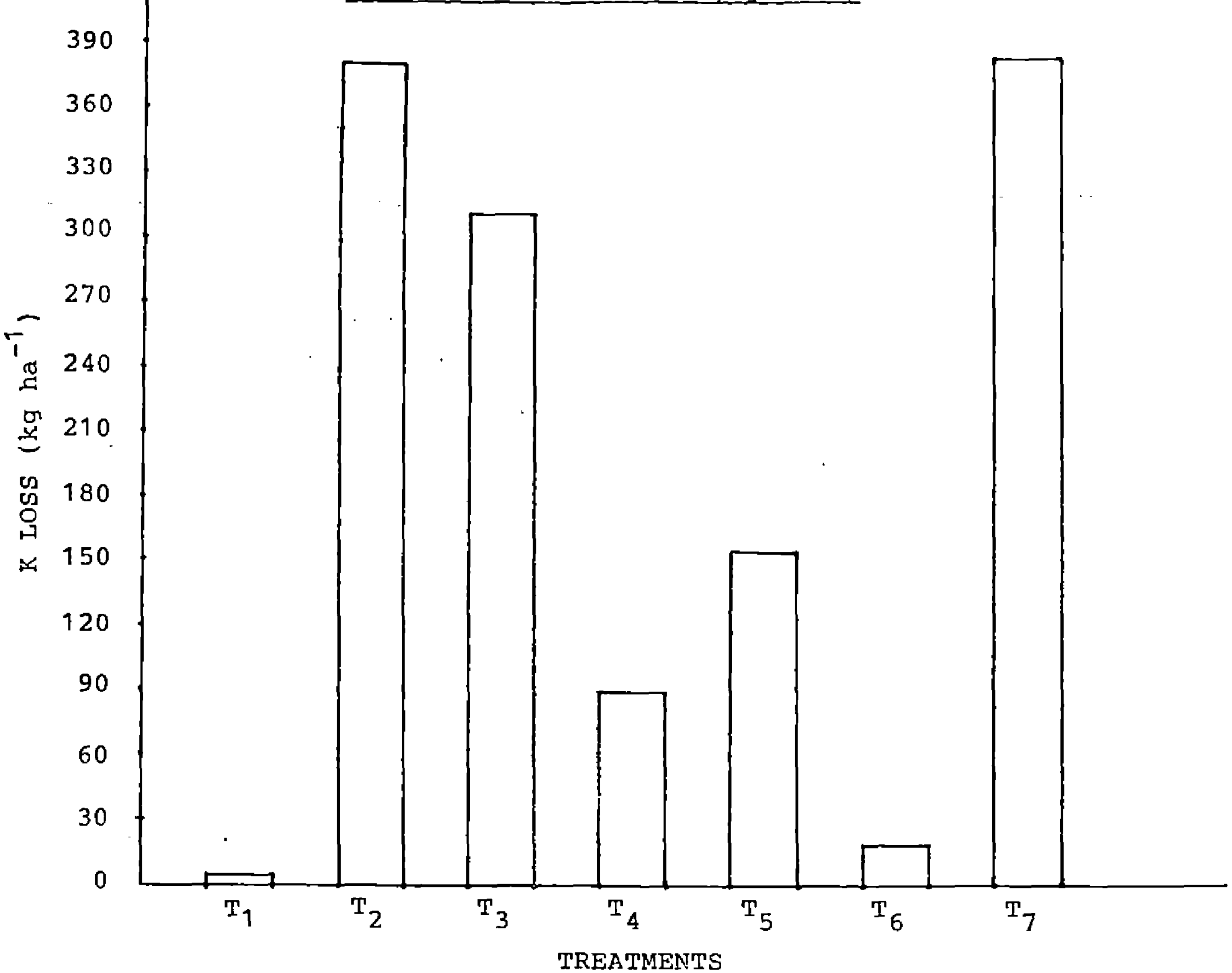


FIG. 9 TOTAL P LOSS(kg ha^{-1})

FIG. 10 TOTAL K LOSS (kg ha^{-1})



produced the highest soil loss and run-off also had lost highest quantities of major nutrients. The reasons for highest nutrient loss in T_7 followed by T_2 are, therefore, explainable. However though T_7 produced the highest soil loss and consequent highest loss of N and K, it was T_2 which registered highest P loss. This is mainly because of the high contents of P in the eroded soils of T_2 (Table 8) consequent to fertilization, than that of T_7 where there was no fertilizer applied. However other intercultivated treatments, though were fertilized, registered substantial reduction in total nutrient loss due to reduced run-off and soil loss.

7. Extent and value of fertility erosion

Table 14 gives the details of the extent and values of soil degradation computed based on the corresponding quantities of fertilizers of major nutrients and their equivalent value in rupees.

Consultation of the table revealed that cultivated bare fallow plot had eroded an equivalent amount of 538, 271, 640 kg ha^{-1} of Urea, Mussoriephos and Muriate of potash respectively which altogether valued Rs.2736. This was closely followed by T_2 with respective values of 488,

Table 14. Extent of fertility-erosion (Rs. ha^{-1})

		Treatments						
		T_1	T_2	T_3	T_4	T_5	T_6	T_7
I	Loss of Nitrogen (kg)	2.136	219.766	188.487	57.134	77.207	8.688	242.142
	Corresponding quantity of Urea (kg)	4.75	488.4	418.86	126.96	171.571	19.306	538.1
	Cost (Rs.)	11.88	1221.00	1047.15	317.40	428.93	48.26	1345.25
II	Loss of Phosphorus (kg)	0.265	66.802	49.688	15.093	22.386	1.737	59.667
	Corresponding quantity of Mussoriephos (kg)	1.204	303.636	225.854	68.64	101.75	7.893	271.222
	Cost (Rs.)	1.20	303.64	225.85	68.64	101.75	7.89	271.22
III	Loss of Potassium (kg)	3.215	377.494	311.721	91.695	151.151	14.523	383.815
	Corresponding quantity of M.O.P. (kg)	5.358	629.156	519.535	152.825	251.920	24.205	639.691
	Cost (Rs.)	9.37	1101.02	909.18	267.44	440.86	42.36	1119.46
IV	Total cost	22.45	2625.66	2182.18	653.48	971.54	98.51	2735.93

Note: Cost of Urea - Rs. 2.50 per kg
Cost of Mussoriephos - Rs. 1.00 per kg
Cost of M.O.P. - Rs. 1.75 per kg

304 and 629 kg ha^{-1} and Rs.2626. The lowest fertility erosion was observed in T_1 by registering a loss of 4.8, 1.2 and 5.4 kg ha^{-1} of Urea, Mussoriephos and Muriate of potash respectively which valued only Rs.22.5. Full pineapple cultivation was very efficient in bringing down the land degradation and the value of fertility erosion was Rs.99 only. Strip cropping was also effective in reducing fertility loss. Grass stripping was better than that of pineapple stripping with corresponding values of Rs.653 and Rs.972, respectively.

Soil conservation is interpreted in its broader sense to include not only erosion control, but also fertility maintenance. Soil conservation was formerly considered largerly in terms of quantity of soil lost or decrease in the soil profile depth. This type of assessment makes it difficult to justify the conservation programme in economic terms. Though the extent and severity of soil erosion is very well clear from the quantity of soil loss as explained in previous tables (Table 4, 5 and 6), an economic analysis is possible only by converting the respective soil loss in a meaning-full way either in total quantity of nutrient lost in eroded soil or in its respective value. The present investigation showed that the conventional mound method of cassava cultivation as practiced in T_2 is causing an annual loss of Rs.2626 through fertility erosion in addition to the loss of 154 tonnes of soil as seen from Table 14. If the fertility erosion proceeds at this rate, in the subsequent years, it would cumulatively retard the performance and yield of crops, leading to erosion, low productivity and poverty. The results of the present experiment also revealed that even in such an erosive, soil degradative treatment, vegetative barriers with pineapple and grass can bring reductions in fertility erosion by 63 per cent and 75 per cent respectively, suggesting the potentials of appropriate agro-forestry system to control erosion and maintain soil fertility.

8. Economics

As destructive sampling was not envisaged in the experiment, the yield of eucalyptus (wood volume) of each treatment was worked out by the formula suggested by Chaturvedi (1973). Table 15 and Fig. 11 provide the economics of each treatment.

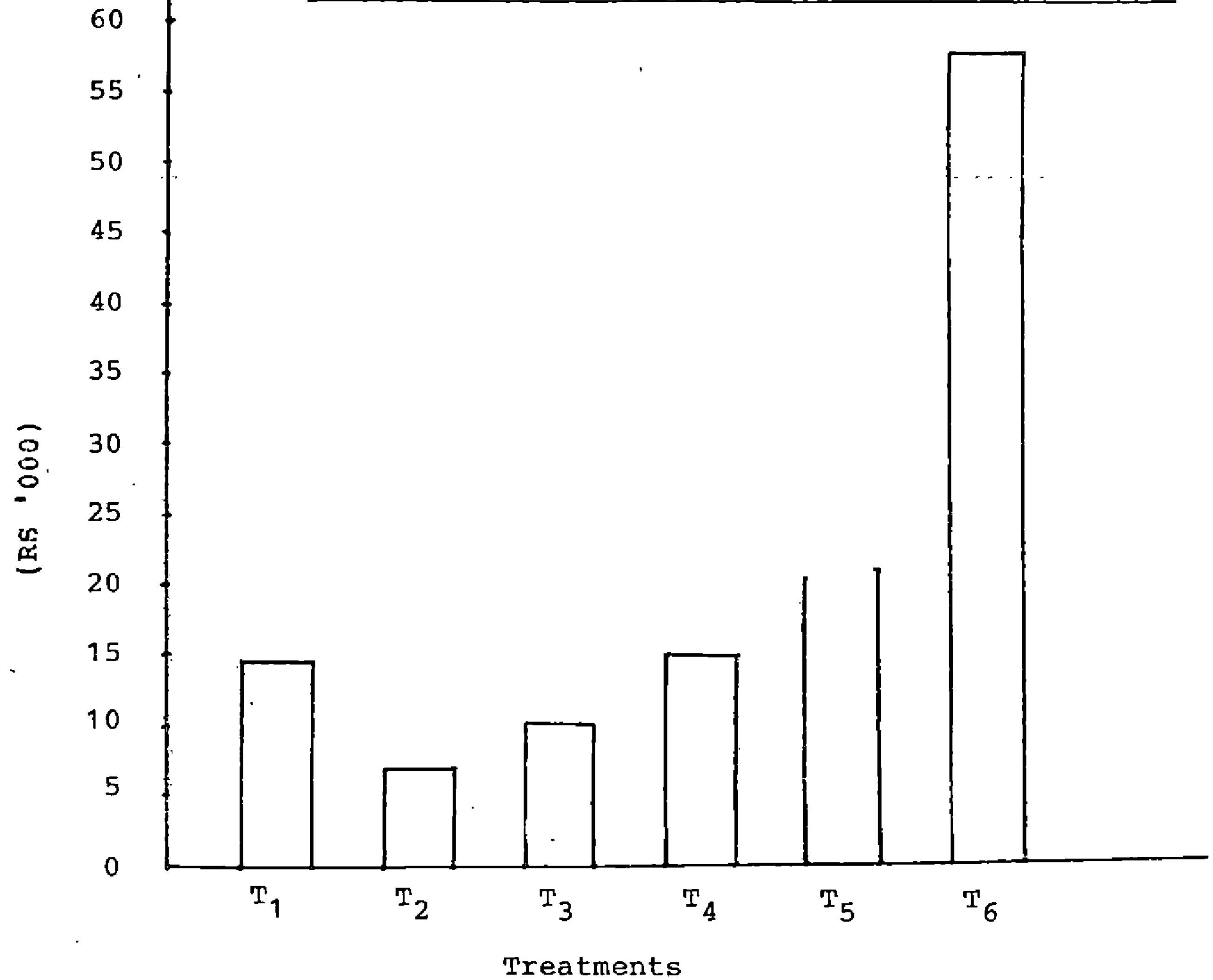
The highest net income of Rs.58350 was recorded by full pineapple cropped (T_6) closely followed by cassava +

Table 15. Economics of cultivation ('000 Rs. ha^{-1}) of each treatment

Items	Treatments						
	T_1	T_2	T_3	T_4	T_5	T_6	T_7
I. Gross income							
1. Eucalyptus wood (Rs.193.0 per cum)	16.15 (83.6)	7.23 (37.5)	8.09 (41.85)	13.04 (67.58)	9.61 (49.8)	17.29 (89.57)	
2. Cassava (i) tuber (Rs.1.0 per kg)		4.23 (4229)	4.85 (4850)	4.46 (4461)	4.06 (4058)		
(ii) stem (Rs.0.1 per stem)		0.57 (5720)	0.57 (5720)	0.41 (4056)	0.41 (4056)		
3. Cowpea (Rs.7.0 per kg)			1.65 (236)				
4. Grass (Rs.150.0 per t)				1.49 (9.93)			
5. Pineapple (Rs.2.0 per kg)					16.50 (8250)	59.99 (29998)	
Total	16.15	12.03	15.16	19.40	30.58	77.28	
II. Expenditure							
1. Labour	1.55	4.10	4.43	4.08	4.37	5.09	
2. Inputs	0.25	0.96	1.36	0.98	5.24	13.84	
Total	1.80	5.06	5.79	5.06	9.61	18.93	
III. Net income	14.35	6.97	9.37	14.34	20.97	58.35	
IV. Percentage contribution from tree component (eucalyptus)	100	78	67	78	37	27	

Note: Figures in parenthesis denote the quantity of economic produce in units given for gross income calculation.
Labour cost was calculated at the rate of Rs.30.0 per man and Rs.28.0 per women.

FIG. 11 ECONOMICS OF CULTIVATION ('000 Rs. ha^{-1})



pineapple stripped (T_5) with a value of Rs.20970. The lowest profit of Rs.6970 was registered by cassava intercropped T_2 preceded by cassava + cowpea T_3 (Rs.9370). The tree alone treatment (T_1) and cassava + grass stripped (T_4) produced comparable profits of Rs.14350 and Rs.14340 respectively.

The analysis of present table in conjunction with Tables 6, 13 and 14 revealed that the net profit of the intercropped treatments was mainly proportional to the decrease in soil loss and consequent fertility erosion and also to the comparative value of the crop produce. T_6 recording a highest profit of Rs.58,350 also stood first in controlling soil erosion and increasing fertility conservation among the intercropped treatments. Here the eucalyptus growth was almost comparable to that of T_1, a tree alone treatment, where soil and nutrient erosion were completely controlled by full tree cropping. Even then the share of eucalyptus in net income of T_6 was only 27 per cent, and the remaining 73 per cent was contributed by pineapple, an efficient soil binding and high value crop which reduced the soil loss to almost 95 per cent over T_2. On the contrary, the lowest net profit of Rs.6970 was recorded by T_2, which registered the highest soil loss among the intercropped treatments. This might have reduced soil fertility and productivity drastically, which resulted in the lowest eucalyptus growth among all treatments and lowest cassava yield among the full cassava intercropped treatments. The significance of erosion control and consequent fertility maintenance is very much evidenced from the increased growth and resultant profit of both trees and crops in T_4 and T_5 where vegetative barriers were provided. Among these treatments though T_5 was slightly less effective in controlling soil loss, it produced 45 per cent increase of profit over T_4. This is attributable to the comparatively high value of pineapple over grass, irrespective of the fact that the share of eucalyptus over the net profit was 30 per cent less than that of T_4. A 35 per cent increase in net profit seen in T_3 over T_2 is in support of the importance of soil cover to improve soil fertility as well as to check at least slightly the soil erosion. Out of the observed difference of Rs.2400 in net income of T_3 only Rs.1650 was contributed by cowpea and the remaining by the increase in productivity of cassava and eucalyptus with the same plant populations of T_2.

The net income analysis gets still more pronounced when the extent, severity and value of fertility erosion are also taken into account (Table 14). If the amount of Rs.2,626 lost consequent to soil fertility erosion is also considered, the profit of T_2 will shrink to a very meager amount of Rs.4345. At the same time compared with net profit of T_2 the net profit of T_4 and T_5 can also considered to have been increased from Rs.14,340 to 16,310 in T_4 and 20970 to 22620 in T_5 consequent to the reduction in fertility erosion through the presence of vegetative strips in this treatments. Net profit of T_6 will reach the highest peak of Rs.60880 consequent to almost complete control of soil degradation.

It can be concluded that when acceptability, profitability and sustainability are considered together, tree + full pineapple cropping comes to be the best agroforestry cropping system for hill slopes of 25 per cent. When cassava is an inevitable component as observed in subsistence agriculture, 15 per cent area interstripped with pineapple followed by grass seems to be the economically and ecologically viable system. Cowpea live mulching is also preferable which can bring down the erosivity to 10 per cent over the worst method of conventional cassava cultivation. When sustainability alone is considered, tree without intercropping is the best treatment.

Summary

SUMMARY

The salient results of the present experiment are summarised below.

1. The month of June recorded the highest rainfall amount, kinetic energy, EI_{30}, EI_{15} values while December recorded the lowest respective values. June was the most erosive month and December the least.

2. Cultivated bare fallow (T_7) produced the highest run-off of 722 mm (35 per cent of the total rainfall). Full pineapple intercropped plot (T_6) gave the lowest of 64 mm (3 per cent of the total rainfall). Among the inter-cultivated plots, full cassava intercropped treatment (T_2) produced maximum run-off of 653 mm. Strip cropping with pineapple (T_5) and grass (T_4) reduced the run-off markedly (397 mm and 296 mm respectively). Cassava + cowpea (T_3) recorded less run-off (539 mm) than cassava alone intercropped.

3. Rainfall acceptance was found to be maximum in T_6 (97 per cent) and minimum in T_7 (65 per cent) of the total rainfall. Full cassava cropped plot (T_2) recorded a rainfall acceptance of 68 per cent while cassava + cowpea (T_3) recorded 74 per cent. Plots with vegetative

barrier strips (T_4 and T_5) absorbed more than 80 per cent of the rain.

4. Cultivated bare fallow (T_7) produced the highest erosion of 163 t ha^{-1} while tree alone (T_1) gave an erosion as low as 0.9 t ha^{-1}, closely preceded by full pineapple cropped (T_6) with 7 t ha^{-1}. Mound method of cassava planting (T_2) eroded 154 t ha^{-1} of soil and was comparable to the bare fallow plot. Even with the mound method of cassava intercropping, introduction of barrier strips with pineapple and grass over 15 per cent areas could reduce the erosion by 60 per cent and 75 per cent respectively. Cowpea live mulching had brought down the erosion by about 10 per cent of T_2.

5. The contents of major nutrients ie. N, P and K in eroded soil as well as in run-off were higher during initial months, reducing gradually towards the final months. In run-off, concentration of N and K were higher compared to P. In general all the intercropped treatments except T_6 showed higher contents of nutrients in eroded soil and run-off.

6. Cultivated bare fallow (T_7) eroded highest amounts of N (242 kg ha^{-1}) and K (384 kg ha^{-1}) while full cassava cropped plot (T_2) eroded maximum P (67 kg ha^{-1}). N and

K losses in full cassava cropped plot were 220 and 377 kg ha^{-1} respectively. Cowpea live mulch could bring down this amounts to 188, 50 and 312 kg ha^{-1} of N, P and K respectively. Tree alone (T_1) recorded the lowest loss of nutrients with 2.14, 0.27 and 3.22 kg N, P and K each. Full pineapple cropped (T_6) lost only 8.7, 1.7 and 14.5 kg ha^{-1} of N, P and K irrespective of the heavy doses of fertilizer application. It was found that by pineapple strips the nutrient loss could be brought down to 77, 22 and 151 kg of N, P and K per ha while with grass strips to 57, 15 and 92 respectively.

7. Extent of fertility erosion in economic terms was found to be maximum in the bare fallow plot amounting to Rs.2,736 and minimum in Tree alone treatment amounting to Rs.22.5 only. Among the intercropped treatments full pineapple cropped plot recorded the lowest with Rs.99 and cassava alone the highest of Rs.2,626. Pineapple strips could reduce the amount to Rs.972 and grass to Rs.653. Cowpea ground cover could reduce the fertility degradation in cassava intercropped plot by almost 25 per cent.

8. The highest net income of Rs.58,350 was produced by eucalyptus + full pineapple cropped plot. This will

even reach a value of Rs.60880 when the nutrient conservation ability of the treatment is also taken into account. The profitability of the other treatments followed the order cassava + pineapple stripped (Rs.20,970) > tree alone (Rs.14,350) > cassava + grass stripped (Rs.14,340) > cassava + cowpea live mulched (Rs.9,370) > cassava alone intercropped plot with a net profit of Rs.6,970.

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*Originals are not seen

Appendices

Appendix-I

Mean monthly weather parameters during the experimental period

Month	Rainfall (mm)	Sun-shine (hr)	Relative humidity (%)	Maximum temperature (°C)	Highest maximum temperature (°C)	Minimum temperature (°C)	Lowest minimum temperature (°C)
<u>1987</u>							
May	95.0	9.0	66	36.1	37.8	24.7	20.5
June	837.7	4.2	83	30.7	35.4	23.7	22.5
July	336.5	5.7	84	30.3	32.0	23.5	20.5
August	388.4	3.7	87	29.6	32.0	23.5	22.5
September	174.0	7.4	79	31.5	34.0	23.9	22.5
October	280.4	6.2	79	31.9	33.8	23.9	22.5
November	224.4	6.7	77	31.6	33.5	22.8	19.5
December	64.6	8.1	70	31.6	33.2	23.3	20.5
<u>1988</u>							
January	0.0	10.4	56	32.4	34.5	22.0	19.8
February	7.8	10.0	56	35.8	37.6	23.1	21.0
March	37.9	9.1	67	35.7	38.0	24.4	21.5
April	145.4	8.8	70	35.1	38.0	24.3	21.5
May	242.6	6.2	76	33.7	35.1	25.4	22.0

AGROFORESTRY MEASURES FOR SOIL CONSERVATION IN HILL SLOPE

By

ALI. P.

ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Science in Agriculture

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1989

Appendix-II

Important rainfall characteristics of major rainy days during the experimental period

Date	Amount (mm)	Duration (hr)	Kinetic energy ($m\ t\ ha^{-1} cm^{-1}$)	EI_{30}	EI_{15}
1	2	3	4	5	6
8-6-87	6.0	0.50	477.1	8.69	8.69
9-6-87	11.0	0.46	720.2	15.08	20.16
11-6-87	25.8	4.83	947.6	18.27	20.85
13-6-87	59.1	5.00	1739.1	19.83	23.80
15-6-87	45.5	3.25	1145.6	69.79	75.60
16-6-87	41.3	8.08	828.8	25.51	27.69
17-6-87	30.3	2.17	716.8	14.33	25.80
18-6-87	50.3	4.67	2100.2	63.75	67.50
20-6-87	7.0	0.83	214.0	1.50	1.71
23-6-87	172.5	8.75	3222.7	47.75	56.63
27-6-87	99.3	10.25	2221.0	33.07	35.49
30-6-87	7.5	0.58	155.1	1.86	3.72
1-7-87	25.2	2.50	965.6	12.55	20.10
2-7-87	13.7	5.67	217.3	3.85	5.89
3-7-87	18.3	1.33	217.3	10.37	18.91
4-7-87	13.2	1.75	217.3	3.10	6.20
5-7-87	23.7	3.08	251.5	4.00	6.36
6-7-87	7.4	0.85	214.0	2.64	3.53
7-7-87	17.4	1.35	440.8	17.74	30.48
8-7-87	12.5	1.27	237.1	8.70	14.40
9-7-87	51.9	3.43	1012.7	45.17	60.11
10-7-87	29.7	1.58	951.0	32.08	38.00
14-7-87	22.5	1.50	894.2	16.18	21.46
15-7-87	14.0	0.72	501.3	15.01	23.02
18-7-87	11.5	1.52	498.2	1.01	1.26
19-7-87	11.7	0.83	708.0	9.56	16.12

Contd.

Appendix-II. Continued

1	2	3	4	5	6
20-7-87	7.2	0.50	214.0	5.30	10.60
22-7-87	1.0	0.08	217.3	4.35	8.70
23-7-87	1.0	0.08	217.3	4.35	8.70
24-7-87	2.5	0.25	217.3	0.65	1.30
25-7-87	15.0	1.50	252.8	8.41	12.68
7-8-87	9.5	1.00	259.8	4.68	4.68
9-8-87	9.5	0.33	259.8	4.67	6.34
10-8-87	3.0	0.17	233.0	1.40	2.08
12-8-87	23.0	3.58	485.8	14.57	20.20
14-8-87	14.5	2.08	233.0	2.79	3.19
18-8-87	30.0	7.00	233.0	2.79	4.66
19-8-87	49.5	7.25	919.4	33.09	33.09
20-8-87	4.5	1.17	217.3	0.54	0.86
21-8-87	12.3	0.83	485.8	4.85	5.70
22-8-87	19.0	1.75	465.6	7.44	7.44
23-8-87	7.0	0.75	427.6	2.56	3.42
24-8-87	37.5	5.33	1313.4	20.22	20.22
25-8-87	34.0	10.67	651.9	1.76	2.64
26-8-87	57.4	6.33	758.5	38.03	38.52
27-8-87	8.3	1.33	220.4	3.58	4.21
28-8-87	8.0	0.92	220.4	2.64	3.84
29-8-87	6.3	0.75	689.3	2.06	3.12
4-9-87	28.0	1.52	539.7	17.81	35.62
16-9-87	7.5	0.75	210.3	2.94	3.36
24-9-87	99.0	14.00	437.5	13.56	14.87
3-10-87	25.0	0.67	608.6	21.86	38.65
12-10-87	14.3	4.83	223.3	1.95	2.60
16-10-87	10.0	0.33	252.8	5.05	6.06
17-10-87	15.0	0.50	252.8	7.58	10.10
18-10-87	49.5	0.75	783.3	26.05	31.71
26-10-87	12.5	0.67	254.0	5.85	9.76
28-10-87	12.0	0.75	474.8	7.11	9.48
30-10-87	60.0	6.00	1555.4	16.84	17.73

Contd.

Appendix-II. Continued

1	2	3	4	5	6
1-11-87	8.0	1.08	259.8	1.43	2.85
8-11-87	44.0	8.25	248.7	14.93	21.34
10-11-87	4.0	0.33	257.6	1.74	1.74
20-11-87	159.3	7.58	1711.2	123.22	136.92
5-12-87	5.0	0.08	279.6	2.79	5.58
7-12-87	6.0	0.08	286.6	3.44	6.88
12-12-87	1.5	0.08	233.0	0.69	1.38

AGROFORESTRY MEASURES FOR SOIL CONSERVATION IN HILL SLOPE

By

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ABSTRACT OF A THESIS

Submitted in partial fulfilment of the requirement for the degree

Master of Science in Agriculture

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1989

ABSTRACT

An experiment on 'Agroforestry measures for soil conservation in hill slope' was conducted at the Instructional Farm, College of Horticulture, Vellanikkara for a period of one year from June 1987 to May 1988. The main objectives of the experiment were to quantify the run-off, soil and nutrient losses as influenced by different agroforestry practices and to evolve economically and ecologically viable agroforestry measures for soil conservation.

Eucalyptus, the tree component was intercropped with cassava and pineapple. The efficiencies of grass and pineapple barrier strips as well as cowpea ground cover along with cassava were also investigated. There were 7 treatments replicated thrice in RBD. The treatments were T_1, eucalyptus alone; T_2 eucalyptus + cassava; T_3 eucalyptus + cassava + cowpea; T_4, eucalyptus + cassava + grass strips; T_5, eucalyptus + cassava + pineapple strips, T_6 eucalyptus + full pineapple and T_7, cultivated bare fallow plot. Daily run-off and soil loss were quantified by installing multi-slot device consisting of 47 slots and brick masonry settling tank specifically designed for the project.

Cultivated bare fallow plot produced the highest run-off of 722 mm (35 per cent of the total rainfall) and soil loss of 163 t ha^{-1} yr^{-1}. Mound method of cassava intercropping was highly deleterious as it registered a run-off of 653 mm and an erosion of 154 t ha^{-1} yr^{-1}. Full pineapple intercropping was effective in reducing run-off and erosion to negligible amounts and gave only 64 mm of run-off and 7 t ha^{-1} yr^{-1} of erosion. Vegetative barrier strips of pineapple and grass to 15 per cent of land area, could reduce the erosion by 60 per cent and 75 per cent respectively over that of T_2. The tree alone treatment recorded the lowest erosion of 0.9 t ha^{-1} yr^{-1}. Cowpea live mulch could reduce the erosion by 10 per cent over the cassava alone intercropped treatment.

Intercropped treatments recorded higher contents of major nutrients both in eroded soil as well as run-off and resultant higher total loss of these nutrients too. cultivated bare fallow lost 242, 60, 384 kg ha^{-1} of N, P and K respectively. These losses were 220, 67 and 377 kg ha^{-1} in full cassava intercropped treatment. Tree alone treatment recorded the lowest loss with respective values of 2.14, 0.27 and 3.22 kg ha^{-1} yr^{-1}. Among the intercropped treatments, full pineapple cropped plot could effectively reduce the loss of N, P and K to very meager amounts of 8.7, 1.7 and 14.5 kg ha^{-1} yr^{-1}. Vegetative strips with pineapple reduced the loss to 77, 22 and 151 kg ha^{-1} yr^{-1} while grass strips further reduced to 57, 15, 92 kg ha^{-1} yr^{-1} respectively. Cowpea live mulching found to lower the nutrient loss to 188, 50 and 312 kg ha^{-1} of N, P and K from the high amounts of loss recorded in cassava alone intercropped treatment.

The highest net income of Rs.58350 per ha was produced by full pineapple intercropped plot followed by cassava + pineapple with Rs.20970. The lowest net profit of Rs.6970 was obtained from full cassava intercropped plot while cowpea cover improved the profit to Rs.9370. The tree alone as well as cassava + grass intercropped plots gave comparable profits of Rs.14350 and Rs.14340 respectively.

The improved nutrient conservation ability of T_4, T_5 and T_6 helped to raise their profit to Rs.16310, 22620, 60880 respectively over T_2. When acceptability, profitability and sustainability are considered, eucalyptus, intercropped with pineapple comes to be the best agroforestry cropping system for hill slopes of 25 per cent. Cassava with pineapple strips followed by cassava with grass strips also seems to be economically and ecologically viable systems. When sustainability alone is considered tree planting without intercropping is the best