Chapter 4

Effective Conservation Farming Systems for the Humid Tropics[1]

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INTRODUCTION

Humid tropics is defined as "the region within a few degrees of the equator where the precipitation exceeds the evapotranspiration for at least 6 months in a year, and the rainfall is sufficiently high and well distributed throughout the year to make it possible to grow perennial crops" (Duckham and Masefield, 1971). Exceptions to this are the equatorial parts of Kenya and Somalia in East Africa, and of Ghana, Togo, and Benin in West Africa. Koppen (1900) included the concept of temperature regime in delineating the humid tropics and defined tropical rainforest as a region in which the temperature of the coolest month is above 18 C and that the warmest month above 22 C. Thornthwaite (1948) combined the temperature regime with that of the precipitation to form a "Precipitation-effectiveness" (PE) index to delineate climatic zones. According to this concept, per humid and humid climates are regions with a PE index of about 64. Manshard's (1968) concept of humid tropics is similar to that of Duckham and Masefield's (1971), and includes those regions with a positive waterbalance for at least 6 months in a year.

The term "farming systems" is rather loosely defined with no uniform concept adopted for world wide use. Lack of a universal definition has often been a bottleneck towards defining research priorities for the

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improvements of farming systems in the humid tropics. For the purpose of this entry "Farming Systems" is defined as "an interwoven mesh of soils, plants, animals, implements, workers, other inputs and environmental influences with the strands held and manipulated by the farmer who, given his preferences and aspirations, attempts to produce output from the inputs and technology available" (Technical Advisory Committee, 1978).

Included in this overall umbrella of the "farming system" are sub-systems that deal with the individual components of the farming system. For example, tillage methods, intercropping (mixed and relay cropping), crop rotation, mixed farming etc. are sub-systems within a given farming system. Farming systems are locally specific, and the research results pertaining to a given farming system may be difficult to extrapolate to another region with a different set of farming systems. The examples of soil-conserving or soil-prone cultural practices referred to in this paper are of the sub-systems that may form components of a specific farming system.

The dominant traditional farming systems in the humid tropics are the "shifting cultivation" and related bush fallow systems (Okigbo and Greenland, 1976). If the shifting cultivation is practiced in a true sense (the "land use factor"[3] is above 5) soil erosion may not be a serious problem. A continuous ground cover, provided through the year around growth of many crops grown simultaneously on the same land, protects the soil against raindrop impact. Soil erosion can become a serious problem, if the land use factor is less than five, and insufficient length of fallow does not permit rejuvination of soil structure.

When the natural vegetation cover is removed for arable land use, soil erosion becomes a serious bottleneck for sustained productivity in the humid tropics. It has been estimated, that to meet the demands for food production in the tropics, the rate of new land development may be as much as 6 to 10 million ha per annum (Boerma, 1975). Another attraction in clearing more land is that in most countries of the tropics, bringing newland into cultivation still constitutes the easiest and most widely practiced method of increasing productivity. Soil erosion problems in the humid tropics follow wherever there is encroachment of forest vegetation by arable land use.

Soil and Climatic Environments

Predominant soils of the humid tropics are Oxisols, Ultisols, and Alfisols in that order of importance. High base status Alfisols cover about 20% of the land area, and low base status of Oxisols and Ultisols about 50% (Sanchez and Buol, 1975). Soil erodibility, as defined in the Universal Soil Loss Equation (USLE), is generally low (Table 1). Under natural conditions, these soils have moderate to high permeability. With exposure to raindrop

[3]The land use factor "L" = C + F/C where C = Cropping Period, and F = Fallow Period.

Table 1. Erodibility (K) of some soils in the humid tropics.

Country	Location	Soil erodibility (K)	References
Nigeria	Ibadan	0.03 to 0.27	Lal (1976)
Ivory Coast	Bouake, Adiopoudome	0.23 to 0.27	Roose (1977), Fauck (1977)
Hawaii	Hawaii	0.0 to 0.37	Dangler and El-Swaify (1976)
Hawaii	Oahu	Low to Moderate	Yamamoto and Anderson (1967, 1973)
Puerto Rico	Mayaguez	0.004 to 0.113	Barnett et al. (1971)
Costa Rica	Turrialba	0.103 to 0.155	Amezquita and Forsythe (1975a)

impact, these soils slake readily and develop an impermeable crust. As a result, runoff increases with continuous cultivation. The erodibility factor (K) of a majority of soils in West Africa has been found to be less than 0.2 (Lal, 1976; Roose, 1977; Fauck, 1977). Soils derived from volcanic ash and those with well-developed structure (Oxisols and Endosols) also have low to moderate erodibility (Barnett et al., 1971; Amezquita and Forsythe, 1975a; Dangler and El-Swaify, 1976).

Available water holding capacity of the surface layer of soils in the humid tropics is generally low (Lal, 1979), therefore the surface layer can reach permanent wilting point within a few days after a heavy rain. Crusting, resulting in a drastic decrease in the infiltration rate, is one of the important factors that increases water runoff and accelerates soil erosion (Falayi and Lal, 1979).

Susceptibility of these soils to erosion by water has been attributed to climatic erosivity rather than to high soil erodibility (Roose, 1977). Rainstorms in the humid tropics are of high intensity (Morgan, 1974; Wilkinson, 1975; Amezquita and Forsythe, 1975b; Lal, 1976; Aina et al., 1977; Bols, 1978). Tropical rainstorms with sustained intensity of 150 to 200 mm $hour^{-1}$ for 10 to 15 min are not uncommon (Lal, 1976).

Scanty information on drop size of tropical rains have indicated that D_{50} (median drop diam) of about 2.5 mm is a common phenomenon (Aina et al., 1977; Kowal and Kassam, 1976). Data of drop size distribution reported in Fig. 1 was obtained at Ibadan in western Nigeria, and represents the median drop size of 170 storms observed for a period from August 1977 to April 1979. Most erosive rains had a D_{50} ranging from 1.70 to 2.55 mm. Storms with this range of D_{50} constituted 44% of rains received. Kowal and Kassam (1976) reported the energy load of about 35 Jm^{-2} mm^{-1} (Joules per meter^2 per mm of rain) of rain at Samaru, in northern Nigeria. At Ibadan, kinetic energy of as much as 64 Jm^{-2} mm^{-1} of rain has been observed (Lal, unpublished data). More research is needed towards characterizing tropical rains for their erosive potential. Direct measurements of drop size distribution, kinetic energy and momentum, and of splash characteristics should provide valuable information on rainfall erosivity of tropical regions.

Range of Soil Loss Tolerance

Soil loss tolerance, as the maximum rate of soil erosion that will permit sustained crop productivity economically and indefinitely, has not been widely investigated in the tropics. The majority of Alfisols have a sub-surface compact gravelly horizon that severely restricts root growth and development (Babalola and Lal, 1977; Vine et al., 1980). Rooting depth for water and nutrient reserves is hardly 15 to 20 cm deep, with nutrients and organic matter content primarily concentrated in the surface 5 to 10 cm layer. On the other hand, Oxisols and Ultisols have a severe problem of high acidity and aluminium toxicity in the sub-soil horizon (Kamprath, 1980).

Quantitative relationships defining the decline in crop yield and the magnitude of soil erosion, for a range of soils and crops, are not available in the humid tropics. Soil loss tolerance for major soil groups in the tropics cannot be determined prior to obtaining this basic information.

Experiments conducted at IITA, continuously for a period of about 10 years, indicate an exponential decline in the yield of maize and cowpea with an increase in cumulative soil loss (Table 2). A significant decline in crop yield can occur with erosion that results in soil removal to an equivalent depth of about 2 cm. This implies that soil loss tolerance for these

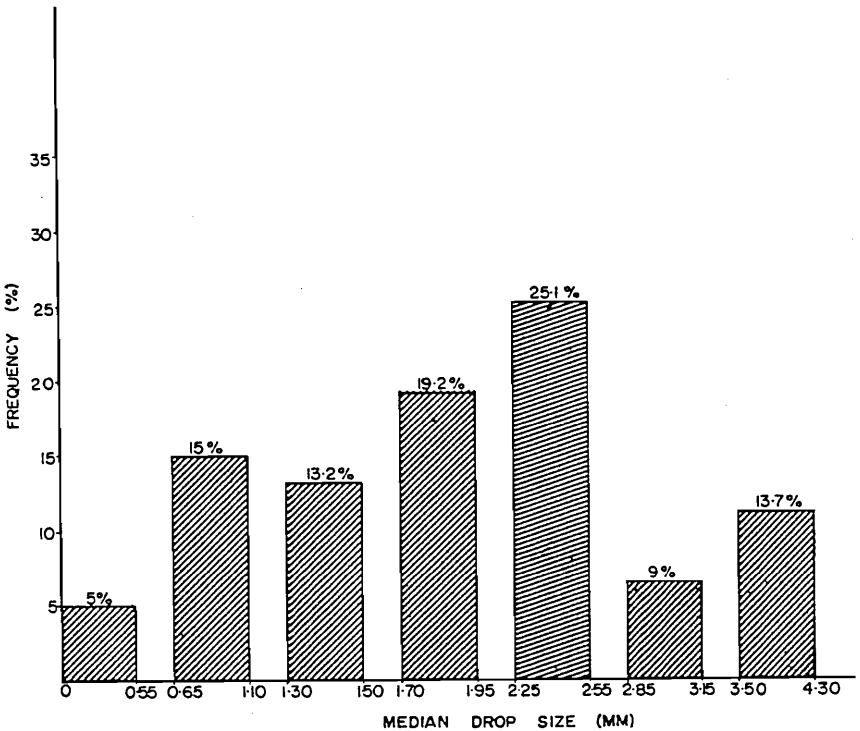

Fig. 1. Frequency distribution of median drop size (D_{50}) of 170 storms recorded at Ibadan, Nigeria, from August 1977 to April 1979.

Table 2. Regression equations relating maize and cowpea. Yield in 1976 to cumulative soil erosion. (R. Lal, unpublished data).

Slope	Regression equation†‡	Correlation coefficient
%		r
(a) Cowpeas		
1	$Y = 0.43\,e^{-0.036X}$	−0.84*
5	$Y = 0.64\,e^{-0.005X}$	−0.97**
10	$Y = 0.49\,e^{-0.004X}$	−0.91**
15	$Y = 0.29\,e^{-0.002X}$	−0.66
(b) Maize		
1	$Y = 6.41\,e^{-0.017X}$	−0.99***
5	$Y = 6.70\,e^{-0.003X}$	−0.99***
10	$Y = 6.70\,e^{-0.003X}$	−0.89**
15	$Y = 8.36\,e^{-0.004X}$	−0.86*

† Y = Grain yield in metric tons/ha.
‡ X = Cumulative soil loss in metric tons/ha.

shallow-rooted Alfisols may be less than 1 metric ton/ha/annum. However, Fauck (1977) observed a somewhat high range of soil loss tolerance for some ferruginous soils in the semiarid regions of West Africa. Research priority should be given to long-term field experiments to establish quantitative relationships between soil loss and crop yield for a range of management systems.

Conservation-Effective Farming Systems

Water transmission characteristics of a majority of soils in the humid tropics are favorable under forest, and when managed with adequate ground cover (Lugo-Lopez et al., 1968; Wilkinson and Aina, 1976; Lal et al., 1978). Though erosion can be severe on lands managed improperly, a crop residue mulch of 4 to 6 metric tons/ha can effectively control soil erosion on steep slopes of up to 15%, and for open-row crops such as maize (Lal, 1976). Runoff and soil loss decreases exponentially with an increase in mulch rate:

$$Y = C_1 M^{-C_2}$$

where M is the mulch rate (metric ton/ha) and C_1 and C_2 are constants. The numerical value of C_2 ranges from 0.25 to 0.75 and that of C_1 from 0.2 to 1.3 for different soils investigated (Lal, 1976). An important concept here is to maintain a good infiltration rate through continuous ground cover. It is not important, therefore, *what* to grow but *how* to grow it. A soil-depleting degrading crop grown with proper soil-conserving techniques such as mulching could give rise to less runoff and soil loss than a soil conserving-crop grown with erosion-promoting practices.

Maintenance of a continuous ground cover, however, is easier said than done. Adaptive long term research is needed to develop sub-systems to meet the residue requirements for adequate cover for a range of soils

and crops in the humid tropics. Though basic principles of erosion control are simple, their effective utilization and adaptation requires additional research in different agro-ecological regions of the tropics. The effects of different sub-systems on hydrological parameters, and on soil and water conservation are discussed below:

(i) Forest Removal:

Deforestation, regardless of the method used, increases water runoff and sediment yield (Hibbert, 1967; Pereira, 1973). However, detailed studies concerning the effects of different methods of forest removal on the components of the hydrological cycle in the humid tropics are not available. This information is necessary for developing suitable methods of land development for arable or alternate uses.

Recent studies conducted at IITA on a 40-ha watershed indicated that surface water runoff was practically negligible from a forested watershed. When 20% of the land was cleared of its forest cover, runoff increased to 20% of the rainfall received. Complete deforestation of the entire watershed resulted in a loss of 27% of the rain as runoff (Fig. 2). Peak runoff rates for identical storms were 0, 0.5, and 2.1 mm hour^{-1}, respectively. Suspended sediment load increased from zero in forested control to about 8 g/liter from the completely cleared watershed.

(ii) Methods of Land Development:

Effects of methods ofland development on soil and microclimate have been investigated in Nigeria (Lal and Cummings, 1979), in the upper Amazon basin in Peru (Suebert, 1975), in Ghana (Cunningham, 1963; Nye and Greenland, 1964) in Malaysia, (Daniel and Kilasingam, 1974) in Surinam (Van Der Weert and Lenslink, 1972; Van Der Weert, 1974) and in Indonesia (Dent, 1979). However, in none of these studies were water balance and sediment load in water runoff monitored as affected by different methods of land development. Nevertheless, most of these studies support the conclusion that mechanical land clearing, compared with manual clearing methods and forested control, is detrimental to soil qualities and has adverse effects on crop yield.

The harmful effects of mechanical land clearing depends on various factors including soil type, antecedent soil moisture content, tree density and their root system, type and weight of the crawler tractor used, nature of the attachment (plane blade, tree pusher, or shear blade), and above all, efficiency of the operator (Fig. 3, 4, and 5). Regardless of the machine used, scraping of the meagre surface soil into windrows, due to inefficient and inexperienced operators, can cause significant yield reductions due both to the loss of fertile surface soil and to unnecessary soil compaction by frequent turnings.

The adverse effects of mechanical clearing on soil is not a debateable issue. The fact remains, that for large-scale land development in the humid tropics, mechanical clearing is inevitable. It is here to stay. Manual labor, if available, is expensive and time consuming. Agronomists and soil scientists should design techniques of mechanical land clearing and soil management so as to minimize their adverse effects. It is more worthwhile to adopt a positive attitude towards this necessary evil than to ignore it.

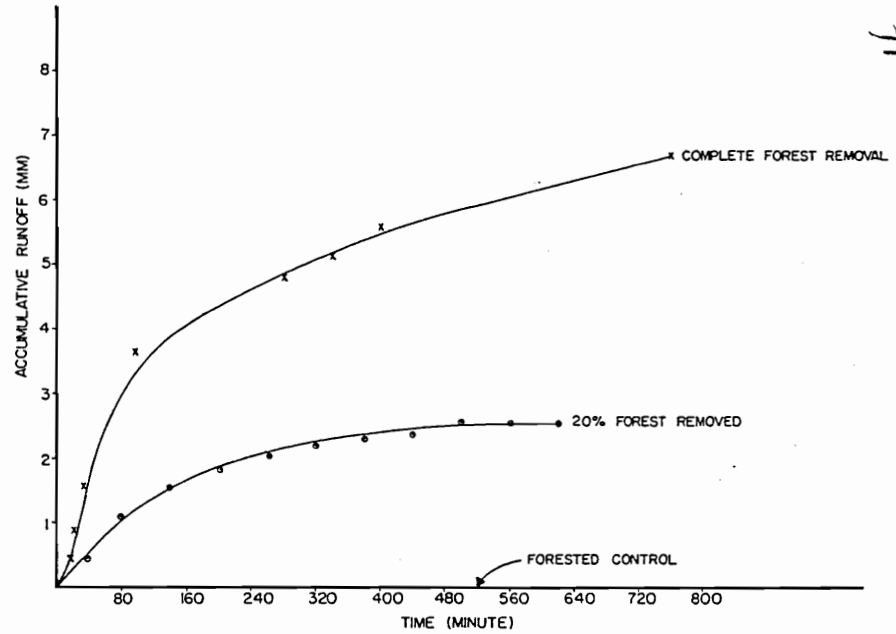

Fig. 2. Effects of forest removal on runoff from two identical 25-mm rainstorms observed in August 1978 and April 1979. Runoff measurements were made with 5:1 triangular weir installed on a 40-ha watershed.

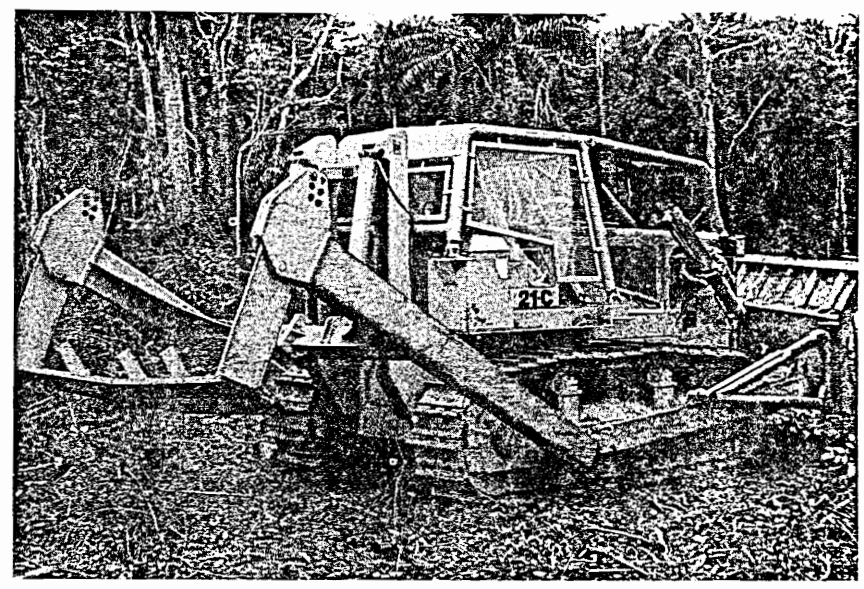

Fig. 3. Mechanical clearing equipment with plane blade and "Tree Pusher" attachments.

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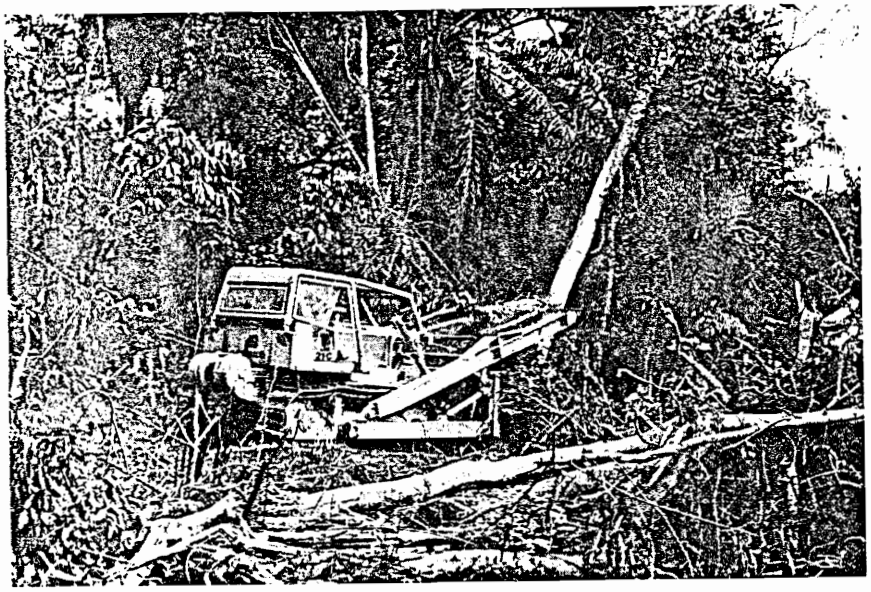

Fig. 4. Mechanical clearing equipment with "Shear Blade" attachment.

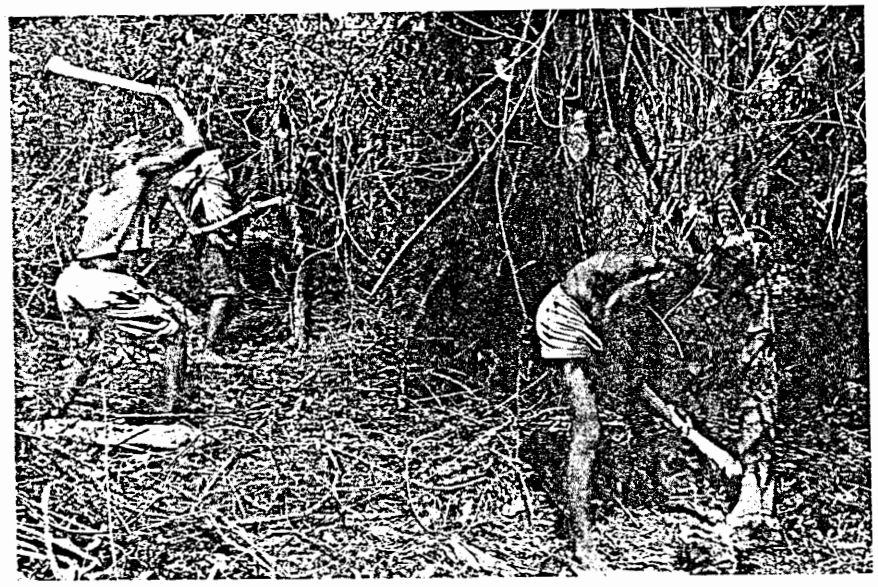

Fig. 5. Manual clearing with axe, cutlass, and chain-saw.

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Table 3. Soil and water loss on 4-ha maize growing watershed as affected by methods of land clearing and tillage systems.

Water-shed	Forest clearing method	Clearing attachments	Tillage system	Time of runoff initiation	Run-off	Sediment density	Soil loss
				hour	mm	g/liter	metric ton/ha
1	Manual	Axe, Chain-saw	Conventional	17.16	4.7	3.1	0.2
3	Manual	Axe, Chain-saw	No-till†	17.22	3.3	2.7	0.1
4	Mechanical	Shear Blade	No-till	17.22	5.1	8.7	0.4
5	Mechanical	Tree Pusher	Conventional	17.18	12.4	17.3	2.1
6	Mechanical	Tree Pusher	No-till	17.22	8.7	7.6	0.7
7	Traditional	Axe-Chain-saw	Traditional	17.46	0.4	2.1	0.01
15	Forested control	None	None	--	0.0	0.0	0.0

† Traditional no-till system.

Effects of methods of land clearing and of post-clearing tillage systems on water runoff, sediment yield, and soil loss from a single storm are shown in Table 3 and Fig. 6. Clearing experiments, on a watershed basis, were conducted on an Alfisol at IITA, Ibadan, Nigeria, from December 1978 to April 1979. Each clearing method was evaluated on a 4-ha plot that had been pre-equipped with runoff (rate and amount) and sediment measuring equipment (Fig. 7). In addition to forested control, effects of six clearing methods and tillage systems were evaluated for water runoff and soil loss. These treatments are listed in Table 3.

An example of the effects of these treatments for a 33-mm rainstorm shown in Table 3 indicate differential effects on runoff and soil loss. As one would expect, there was no runoff in forested control. Percent of the rainfall lost as water runoff ranged from 1.2% for traditional methods to as much as 37.5% for mechanical land clearing with a tree pusher and a conventional tillage system. Whereas manual clearing with no-tillage was extremely effective in runoff control (10%), mechanical clearing with a shear-blade followed by a no-tillage system produced significantly less runoff than the tree pusher treatment followed by conventional tillage (15.5 vs. 37.5%). Peak runoff rates were 1, 10.1, 14.2, 28.4, 29.2, and 1.3 mm $hour^{-1}$ for watersheds 1, 3, 4, 5, 6, and 7, respectively. (Treatments for different watersheds are listed in Table 3). Land clearing with a shear-blade left a considerable amount of leaf litter on the soil surface. In addition, roots and stumps left in the soil provided additional protection against the shearing effect of water runoff. Consequently, sediment density and total soil loss in the shear blade treatment was drastically reduced compared with the tree pusher method of forest removal (Fig. 8 and 9).

Choice of methods of land clearing also depends on the intended land use. If perennial crops were to be planted, a suitable method would be the one that allows a gradual replacement of forest canopy of lesser economic importance with that of an economical plantation crop without soil disturbances and without removal of the biomass. Similar method can be adopted for pasture establishment. For these purposes, use of some

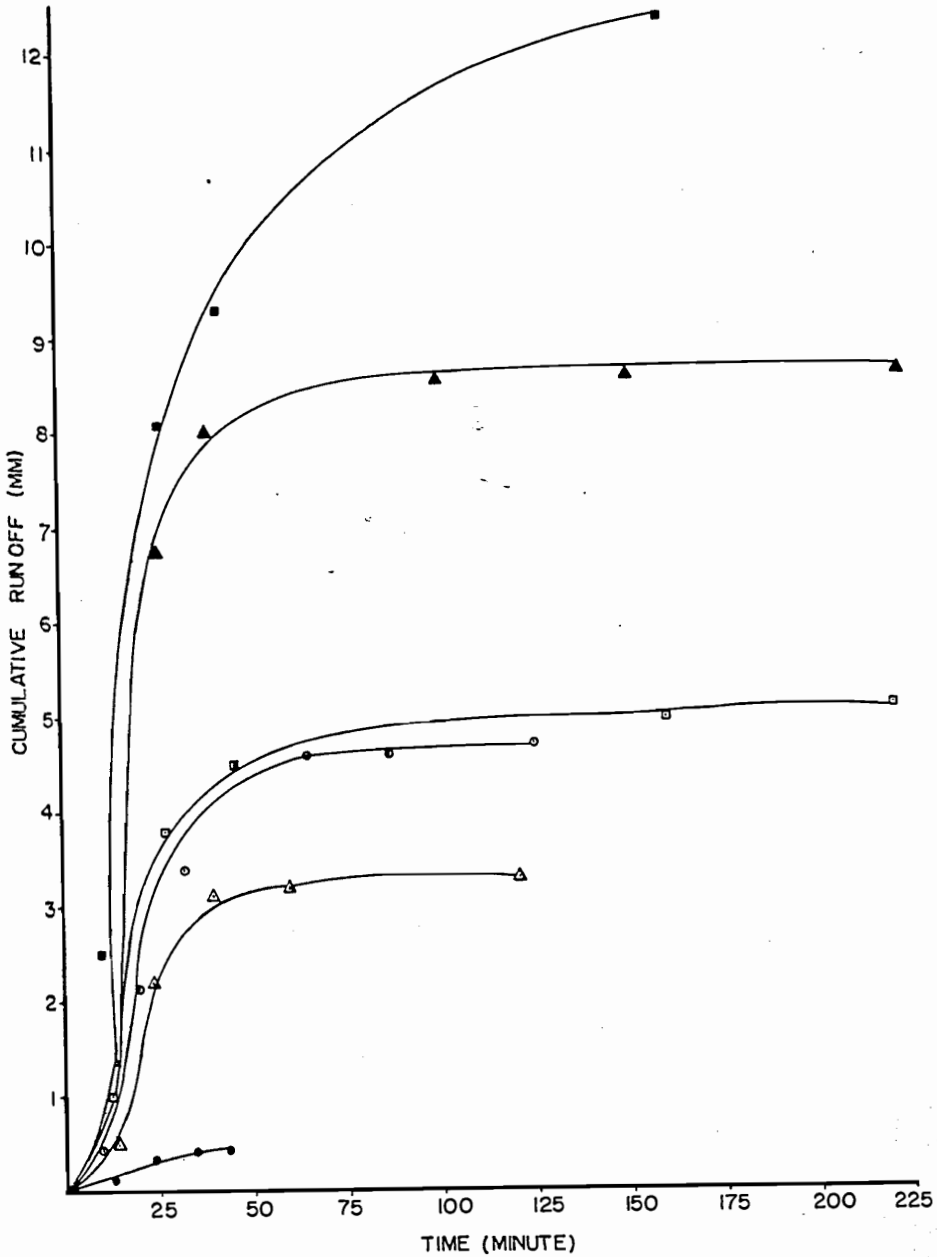

Fig. 6. Effects of methods of forest removal and post-clearing management on accumulative runoff from a 33-mm storm observed at Ibadan on 17 June 1979. Runoff measurements were made on 4-ha watersheds. ○—○ Manual clearing followed by (fb) Conventional tillage; △—△ Manual clearing fb no-tillage; □—□ shear-blade fb no-tillage; ■—■ Tree Pusher fb conventional tillage; ▲—▲ Tree Pusher fb no-tillage; ●—● Traditional farming system.

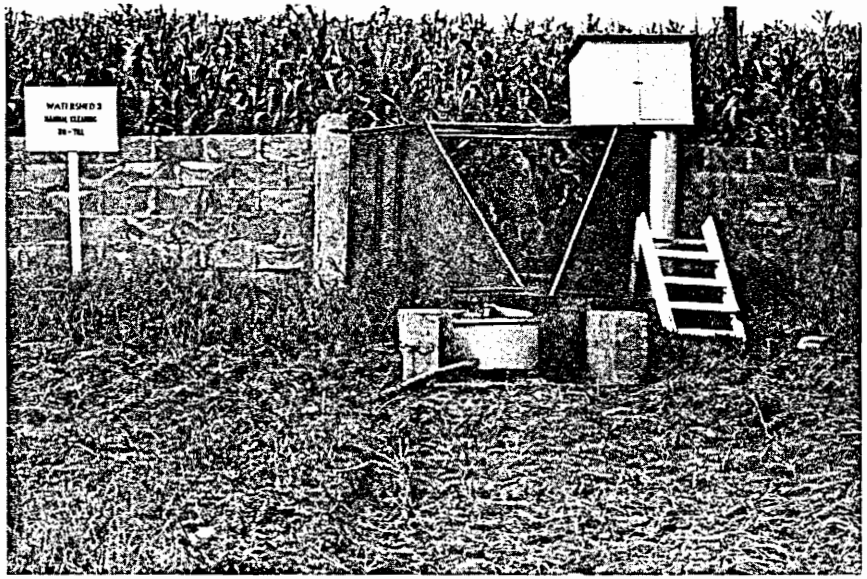

Fig. 7. An H-Flume with water-stage recorder (in the box), and runoff sampling device.

Fig. 8. Soil erosion from a watershed cleared with "Tree Pusher" and conventionally plowed for maize production.

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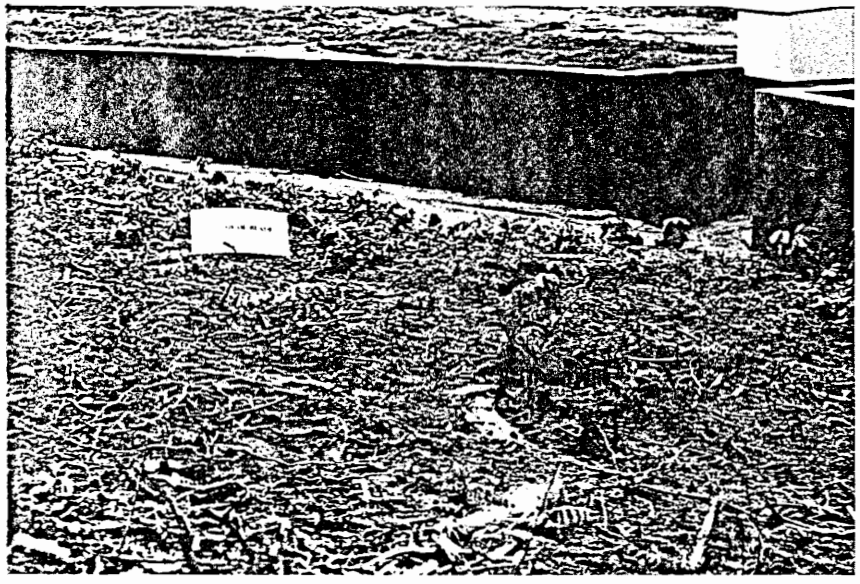

Fig. 9. Soil erosion from a watershed cleared with "Shear-blade" and un-tilled for maize production.

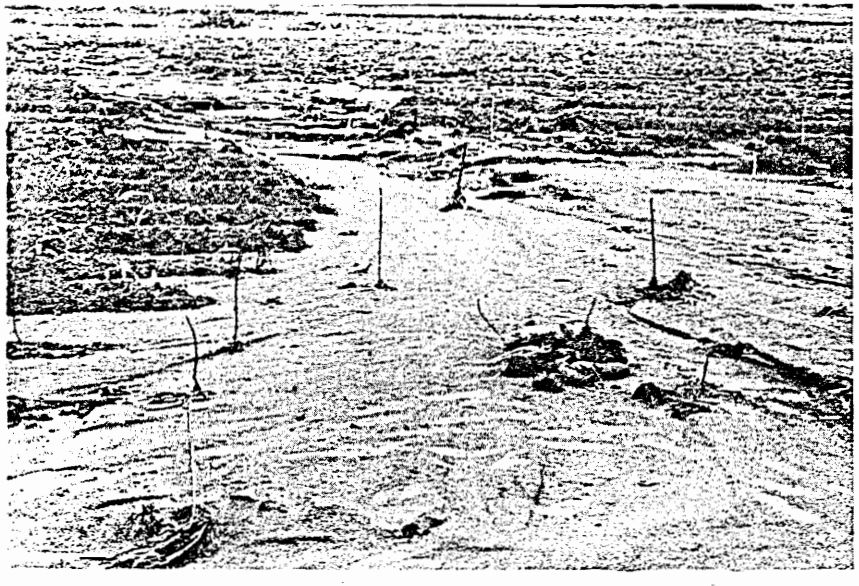

Fig. 10. Soil erosion, on contour ridged lands, caused by a 15-cm exceptional storm recorded in Ibadan on 20th April 1978.

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Table 4. Cost of post-clearing development for conventionally tilled and terraced 5-ha watershed on Alfisol at IITA. (After Couper et al., 1979).

Operation	Professional services (man days)	Labor (man-days)	Equipment (days)	Total cost (U.S. $)
Grid survey	3	6	--	48
Mapping	0.5	--	--	12
Surveying and placing contour banks	2	8	--	64
Grading contour banks	0.75	--	0.75	384
Waterway construction (D_5)	0.5	--	0.5	320
Rome plowing	2	--	2	1,280
Removing tree roots	--	12	--	48
Total cost 5 ha			U.S.	$2,156
Post-clearing development cost/ha			U.S.	$ 431

All prices at 1974 level.

chemicals to suppress and kill the existing vegetation cover may be beneficial and economical (Brun et al., 1961; Philip, 1962; Leifstingh, 1965; Marty, 1966). It is the arable land use that requires complete removal of surface biomass to facilitate mechanical seeding and tillage operations, and that accelerates water runoff and soil erosion.

(iii) Tillage Systems:

Concept of seedbed and its preparation has drastically changed since the economical availability of some herbicides. Seedbed preparation, for good seed germination and seedling establishment that leads to a minimum competition with weeds, could be attained by mechanical, chemical, or biological means. Conventional methods of mechanical seedbed preparation have not been effective in erosion control even on terraced and ridged lands (Fig. 10). Terraces are expensive to install and maintain. Data in Table 4 shows that the post-clearing development cost of installing terraces can be as much as U.S. $430/ha. Farmers are reluctant to invest large sums of money for an undertaking whose returns are uncertain. Moreover, 10 to 15% of the land surface goes out of production. In addition, regular maintenance of terraces, for safe disposal of water runoff at reduced velocity, is indispensable.

Given that terraces function effectively, inter-terrace erosion can still be serious on soils susceptible to water erosion. Data in Fig. 11 shows runoff from a 5-ha terraced watershed growing maize with conventional tillage compared with an equivalent watershed growing maize with a no-tillage system. The no-till watershed was not terraced, since crop residue mulch provides the needed protection against erosion. These watersheds have been growing maize for eight consecutive crops since 1974. Both watersheds were manually cleared of the secondary forest vegetation. Total water runoff from the terraced watershed was 60 to 70 times more than the no-till watershed. In addition, the sediment load in water runoff from the terraced and mechanically tilled watershed was five times that from the no-till watershed (2.5 vs 0.5 g/liter).

Adaptive research is urgently needed, for different soils and agro-ecological regions, to develop cropping/farming systems to explore the potential of the no-tillage method of seedbed preparation. Similar to that of mechanical seedbed preparation, the no-tillage method can be effective only if it is adopted as a package. The package of cultural practices for the no-tillage system may be drastically different than for the mechanical

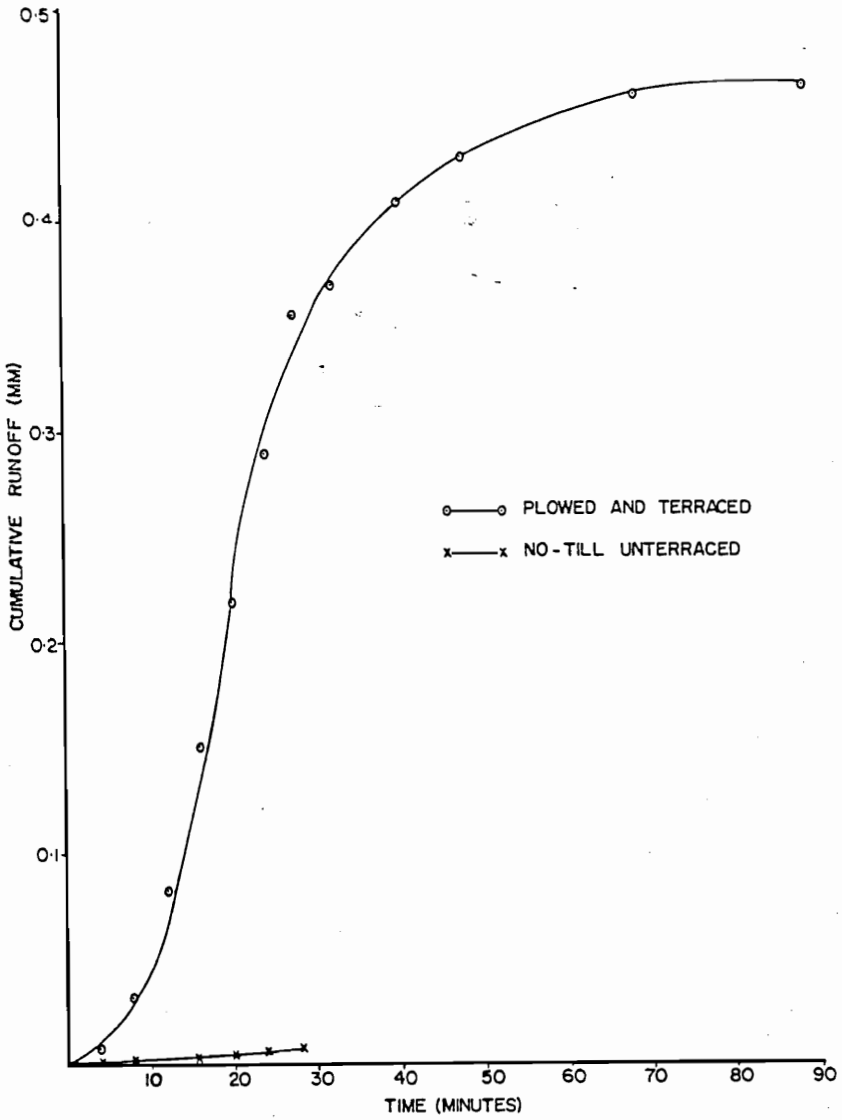

Fig. 11. Effects of tillage systems on runoff from a 23-mm rainstorm recorded at Ibadan, Nigeria, on 17 June 1979. Conventionally tilled 5-ha watershed is terraced whereas no-till watershed is not.

Table 5. Soil losses and runoff under cassava monoculture and mixed cropping of cassava and maize during 1975, at Ibadan, Nigeria. (Adapted from Aina et al., 1977).

	Soil loss (metric tons/ha/annum)		Runoff (%) of rainfall	
Slope	Cassava	Cassava and maize	Cassava	Cassava and maize
%				
1	3	3	18	14
5	87	50	43	33
10	125	86	20	18
15	221	137	30	19

land preparation methods. Research information is needed for adequate methods of weed control, suitable cropping systems, (including crop sequences, relay and mixed cropping), balanced fertilizer application (method, rate, type, and timing of fertilizer use), adequate crop residue, suitable farm machinary to seed through trashy uneven soil surface, and for plant protection. No-tillage system can be effectively used for erosion control if applied with a recommended package of cultural practices, a package that will be different for different crops and soils.

(iv) Crop Sequences and Crop Combination:

Cultural practices that support good crop growth and provide luxuriant and continuous ground cover are less susceptible to soil erosion. Good crop husbandry including balanced fertilizer application, optimum plant population, and adequate crop protection minimize the risks of soil erosion (Hudson, 1976). There is no substitute for good crop husbandry.

Mixed and relay (seeding through a standing crop) cropping systems with multi-canopy structure, and those that provide a continuous vegetal cover throughout the year, protect soil against direct raindrop impact and decrease runoff and soil erosion. Aina et al. (1977) observed a significant decrease in water runoff and soil loss from a field of maize and cassava intercropped compared to maize and cassava cropped separately (Table 5). Some cassava varieties take as much as 50 to 60 days to develop 50% ground cover. Mixed cropping of maize with cassava and other crops provide an early ground cover and prevent soil erosion.

Though mixed and relay cropping systems are important components of the traditional farming systems in the humid tropics (Okigbo and Greenland, 1976), their practicability decreases for commercial mechanized farming. It has been observed (Dr. B. T. Kang, personal communication), that the "land equivalent ratio" decreases with increase in inputs of commercial fertilizers. This implies that whatever the benefits of mixed cropping in the traditional systems, the production per unit area and per unit land surface decreases with increase in fertilizer and other farm inputs. Moreover, mixed and relay cropping are not practical with mechanical operations of seeding and harvesting.

(v) Mixed Farming and Controlled Grazing:

Easily available research information, towards quantitative effects of grazing and pasture management on water runoff and soil erosion in the humid tropics, is scanty. It is generally speculated that soil erosion on

properly managed pastures, with controlled grazing, is not as serious as from arable lands planted to open-cultivated row crops. However, there is no quantitative data available in support of this argument. There is no doubt, however, that planned land use of forested slopes with well managed pastures and controlled grazing can result in economically and hydrologically productive watersheds. Excessive grazing, on the other hand, has resulted in denudation of the vegetative cover and in accelerated soil erosion (Greenland and Lal, 1977). Pereira (1973) reported 40% of rainfall lost as runoff from heavily grazed watersheds in East Africa. The penetration of rainfall into the trampled soil was slight, with no wetting observed below 0.5 m depth. On the other hand, the wetting front was observed to a depth of 0.5 to 1.25 m on an equivalent watershed with controlled grazing. Consequently, peak flows of water runoff were accordingly reduced. From the point of view of soil and water conservation, grazing pressure should not exceed one cow/2.4 ha (Pereira, 1973).

Reclamation of Eroded Lands

The conclusions drawn from a critical appraisal of the large-scale mechanized development schemes in Africa and elsewhere in the tropics are not encouraging. The well-known "groundnut scheme" in Tanzania (Wood, 1950; Wild, 1967), and the Niger Agricultural Project in Nigeria (Baldwin, 1957) are some of the examples of such miscalculated ventures. Nevertheless, failure of these schemes has not deterred similar ventures undertaken and currently being planned elsewhere. Planning and execution of such schemes, with utter disregard of the soil conditions and other environmental facotrs, have lead to widespread barren and unproductive lands where lush green forest once prevailed (Greenland and Lal, 1977). Whereas caution must be exercised in unthinking and poorly planned development of forested regions, research must also be undertaken to develop efficient methods of restoration of those eroded and degraded lands.

Use of cover crops and suitable tree species followed by controlled and planned grazing has been found to restore the fertility of eroded lands. Pereira and Beckley (1952) observed that regeneration of tropical grasslands in East Africa was more effective when the ground was less disturbed compared with deep ripping with heavy machinary. Full recovery, after various grass and leguminous crop covers, took 2 or more years of fallowing (Pereira and Thomas, 1961). Grazing capacity after full recovery was as good as, or better than obtained from plowing and reseeding. At Muguga in Kenya, Pereira and Dagg (1967) reported that runoff and soil loss from bermudagrass [*Cynodon dactylon* (L.) Pers.] pastures on 10% slope in a 1,000-mm rainfall region were negligible.

Reforestation of eroded watersheds is another effective measure of reclaiming eroded lands. An example of restoration of tropical watersheds similar to that of Tennessee Valley is not available (Tennessee Valley Authority, 1962). Following reforestation with appropriate species, surface runoff can be safely disposed by diversion channels, cut-off drains, or contour furrows. Well-planned and properly equipped hydrological investigations, with adequate monitoring of stream flow and sediment load, are needed to quantify the restorative effects of different tree species.

Planned watershed management systems should be developed where tree crops can be grown in association with seasonal row crops. In an integrated watershed management system, different crops are grown on various toposequences or contours starting from the valley bottom with rice to tree crops at the crest (Okigbo and Lal, 1979). There is a need for research into better methods of forest exploitation in the agrisilvicultural system which ensures efficient utilization of soil and water resources in the humid tropics.

Effects of a range of leguminous and grass fallows on restoration of an eroded alfisol have been investigated at IITA (Lal et al., 1979). Improvements in soil characteristics under *Brachiaria*, *Paspalum*, *Cynodon* spp., *Pueraria*, *Stylosanthes*, *Stizolobium*, *Psophocarpus*, and *Centrosema* were compared with that of weed-fallow control. There were significant improvements in soil organic matter, total cation exchange capacity, infiltration rate, moisture retention at low suctions, and soil bulk density under various grass and leguminous fallows compared with control. There is a need to monitor runoff and water loss on a watershed basis for evaluating the effectiveness of a range of ground cover on restoration of soil fertility, and in improving hydrological balance in favor of recharge and soil-moisture storage.

RESEARCH PRIORITIES

Basic research, on a pilot project basis, is needed to develop suitable methods of forest clearing and land development. These investigations, on a watershed basis, should be conducted for a range of soils and agro-ecological environments. Basic data on soil and microclimate should be related to hydrological characteristics and sediment load so that results can be extrapolated for broader applicability.

Adaptive research is also needed to develop local-specific farming systems to ensure adequate quantity of crop residue mulch for a continuous ground cover to protect the soil against raindrop impact.

In order to exploit fully the benefits of the no-till system, practically oriented research is needed to develop a package of cultural practices to meet the specific requirements of these systems.

Plantation crops, pastures, and agroforestry have an important role to play in soil and water conservation in the humid tropics and for sustained productivity from these harsh environments. Planned hydrological investigations are needed to compare the productivity of different farming systems in relation to proper use of soil and water resources.

Effective measures for soil and water conservation may only be developed if research information is available to establish a quantitative relationship between the magnitude of soil erosion and of loss in productive potential of an environment. To date, there are few investigations that indicate the seriousness of the soil erosion problem. Long-term well-planned and properly equipped studies are needed to obtain this information.

SUMMARY AND CONCLUSIONS

Soil erosion becomes a serious problem in the humid tropics when traditional farming systems are discarded in favor of continuous mechanized cultivation of seasonal row crops. The potential high erosion hazard of this ecological region is attributed more to climatic erosivity than to soil erodibility. The energy load of tropical rains (Jm^{-1} mm^{-1} of rain) is more than temperate rains because of big drop size.

Deforestation for arable land use increases runoff and soil erosion by an order of magnitude compared with a forested watershed. Since development of forested lands is inevitable, mechanical means of land preparation are increasingly being used. Manual methods of land development, though causing less damage to soil structure, are expensive and time consuming. Compared with the tree pusher and the plain blade, clearing with the shear blade followed with a no-tillage system produces drastically less runoff and erosion.

The no-tillage system with crop residue mulch is an effective erosion control practice, provided it can be adopted as a package of all cultural practices that make it work. Continuous ground cover provided by relay and mixed cropping systems has a significant role to play in soil and water conservation and minimizing risks against vagaries of climate and traditional farming systems. Good crop husbandry is an effective soil conserving practice.

Basic research is needed to quantify soil and climatic environments for adaptation of no-tillage system and towards methods of forest clearing and land development. Hydrological investigations, to be conducted for a reasonable length of time, should be planned on a watershed basis.

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Chapter 5

Development of Areas of Shifting Cultivation in North Thailand "Thai-Australia Land Development Project"[1]

JOHN M. SCHILLER, CHAIYASIT ANECKSAMPHANT, AND SUWIT SUJANIN[2]

INTRODUCTION

Population pressure and a land shortage in the lowlands of North Thailand, has resulted in a spontaneous movement of people to the uplands and highlands of the region. This has meant a change from the traditional 'wet rice' cultivation to rainfed cropping. Initially the cropping system practiced was the typical 'slash and burn' or 'swidden' system. On a cycle of 8 to 10 years or more, this is generally regarded as a stable system and in fact may be the most appropriate for this zone, at least for the forest regions (Kalpage, 1976). However, increasing population pressure due to continued migration[3] from the lowlands as well as

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[3] Unofficial estimates have suggested up to half a million families have moved to the upland and highland zones.

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