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Structural adjustment policies and the management of soil- and forest resources in Tanzania

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Preface

This supplement of the Norwegian Journal of Agricultural Sciences contains papers presented at a seminar on "Structural adjustment policies and management of soil- and forest resources in Tanzania". The seminar was held on 2nd and 3rd August, 1994, at Sokoine University of Agriculture, Morogoro, Tanzania, with financial support from the Norwegian Research Council through the "Ecology and Development Programme". The papers presented at the seminar, with the exception of three papers, reported results from various ongoing research projects in Tanzania under the "Ecology and Development Programme".

We gratefully acknowledge the contributions made by the local organising committee, consisting of Dr. M. Kilasara (chairman), Dr. P.N.S. Mnkeni, Mr. Y.M. Ngaga and Anna Temu of the Sokoine University of Agriculture, in making this seminar a success and thereby enabling us to bring out this special supplement.

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Structural adjustment policies and the management of natural resources

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The Ecology and Development Programme aims at identifying effects of Stabilisation and Structural Adjustment Policies (SAP) on the management of soil and forest resources in Tanzania. For studying the effects of policy changes on soil degradation and deforestation, economy-wide models are necessary. Tentative conclusions indicate both positive and negative environmental effects of the SAP. Negative effects may to a large extent be dealt with through policies directed at the specific problem, e.g., where the SAP increases the profitability of extracting an open access resource this can effectively be addressed by introducing a tenure regime which restricts access to the resource. This points to the possibility of designing environmental policies that are compatible with the aims of structural adjustment.

Key words: Economy-ecology models, structural adjustment policies.

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In response to the World Commission on Environment and Development report (WCED, 1987), the Norwegian Research Councils initiated a major research programme, called "Economy and Ecology: Management Tools for Sustainable Development". The aim was to address research issues raised by the report.

The Commission pointed to a number of threats to local and global sustainability. While many of the threats, like global atmospheric warming, are shared by the whole global community, some are either more specific to the rich countries, e.g., water pollution from high fertiliser usage in agriculture, or to developing countries, e.g., deforestation.

One of the five sub-programmes of the Economy and Ecology programme was charged with addressing the emerging sustainability problems, specifically in the context of developing countries, i.e., our Ecology and Development programme.

In the developing world in general, and Africa in particular, the major threat to sustainable development is through degradation and over-exploitation of soils, pastures, forests, fisheries, etc. The economies of developing countries will continue to depend on these natural resources for long time to come.

The WCED pointed to the close interlinkages between poverty and natural resource degradation – indeed to poverty as the cause of degradation. Besides, the commission also assigned a role to other causal factors, such as, institutional failures creating open access to natural resources vulnerable to over-exploitation, and policies and tenure regimes which may in some other ways often stimulate the over exploitation of resources[1]. Several studies have indicated alarmingly high rates of soil erosion, soil mining, deforestation and desertification. Some of the highest estimates may be too alarmist, but there is still plenty cause for concern.

The WCED stressed that for understanding the causes of, and finding the remedies for such threats to sustainability, an interdisciplinary approach is needed. More specifically there was a need for social scientists and natural scientists to work together. Developing modalities for such interdisciplinarity is one of the main objectives of the Economy and Ecology programme.

In the same decade as we got the WCED report, a large number of developing countries adopted stabilisation and structural adjustment programmes (SAPs), mostly under pressure from the IMF and World Bank for correcting the existing and anticipated serious economic imbalances and poor economic performance of the reforming countries.

CRITICISMS OF SAPs

The SAPs have been highly controversial. Opponents have blamed them for having been poorly designed and hence unsuited for achieving the stated objectives, i.e., that the SAPs will neither remove imbalances nor improve the economic performance of the adjusting countries. A second line of criticism points to the high social costs of adjustment, which have been unfairly distributed – too much of the cost of adjustment has had to be carried by those already worse off. Both of these lines of criticism have been subjected to considerable research efforts. A third, and more recent line of criticism, however, is the claim that the SAPs increase pollution and resource degradation problems by ignoring the environmental concerns. This assertion is primarily based on the assumptions: (1) the need for short term increase in export earnings can only be satisfied by increased exploitation of natural resources, and (ii) the severe cuts in government spending called for by the SAPs, will reduce possibilities for enforcing regulations aimed at conserving resources (Reed 1992).

Proponents of the SAPs have, however, claimed that removing institutional constraints in the economy and "setting prices right" would contribute significantly to reduced resource degradation, particularly in cases where adjustment ends under-pricing of resources (e.g., Thampapillai & Anderson 1991, World Bank 1994). Thus the SAPs may actually have favourable impact on the environment. However, by and large, the issue still remains unresolved.

By the time the Ecology and Development programme was initiated in 1990, very little empirical research had actually been carried out on the environmental effects of structural adjustment policies, the major exception being the work of Cruz & Repetto (1992). The programme, therefore, was aimed at filling knowledge gaps in this field.

In the Ecology and Development Programme Tanzania, Zambia and Ethiopia were chosen as the cases to be studied. The main emphasis of the programme has, however, been on Tanzania, which has been the more consistent reformer among the selected countries. Soil degradation and defore-

[1] By the term over-exploitation in this context is meant a level above the socially optimal exploitation level. Thus, all levels of deforestation may not necessarily be regarded as bad from the point of view of sustainable development. It is the speed at which deforestation seems to be occurring in Africa, and elsewhere, that gives cause for alarm.

station were seen as the biggest natural resource management problems faced by the three countries. The impact of economic reform policies on these problems was therefore chosen as the main focus of the programme.

More recently a number of institutions and organisations have shown increased interest in this aspect of environmental impact assessment, e.g., the World Bank and the World Wide Fund for Nature (WWF), both of which have initiated studies in Tanzania and several other countries.

PROBLEMS IN MEASURING THE EFFECTS OF SAPs

Measuring the impact of SAPs on environment and resource management is not easy. It is neither possible, nor correct, to simply find some set of parameters indicating soil degradation or deforestation and then compare their values at one point of time (before adjustment) with their values at some other time (after adjustment). This is due to the following reasons:

- Comprehensive baseline data to be used for environmental indicators, such as, soil degradation and deforestation are incomplete, and those data that exist are often difficult to obtain.

- Determining the cut off date by which the SAP has been completed, and all its effects have been realised is problematic. A SAP is not a once for all shock therapy of a complete set of adjustments implemented simultaneously. It should be seen more as a long term process. Moreover, the short term effects of SAPs may be assumed to be very different from the long term effects. The initial stabilisation policies will usually have contractionary effects – perhaps even leading to negative economic growth – while in the longrun this should give way to accelerated positive growth rates. This is partly due to significant lags in adjustment of economic agents to new policies. For example, in case of a policy change aimed at improving the profitability of agriculture, it may take more than ten years before the full effects on aggregate agricultural supply of this change are realised (Binswanger 1992). In the case of environmental variables too, there will often be significant lags between cause and effect. The long lags between emission of "greenhouse gases" and global warming may be a case in point.

- Furthermore, the SAPs are not the only thing that has happened to the economies of East Africa over the last decade. There have been fluctuations in weather, in international commodity prices, etc., and the population growth rate is still in excess of three per cent annually. Comparisons between pre-adjustment and post-adjustment situations are therefore hardly relevant. More relevant are comparisons between "with and without adjustment" situations. In the "with versus without" analysis the description of the "counterfactual" – the development path without SAP – is a major problem. The Tanzanian economic trends in the early 80's were hardly sustainable – which is exactly why the SAPs were undertaken. The economy could not have continued with "business as usual", because it became impossible to finance the ever increasing foreign deficits without a SAP. Thus even without a SAP, major adjustments would have been inevitable. However, the description of the realistic alternative development path (without SAP) is highly controversial, e.g., in determining which policy adjustments it should incorporate. It is impossible to know what would have happened if SAP had not been implemented the way it was.

The preceeding discussion has outlined some of the more basic problems inherent in analysing the impacts of a set of economic reform measures on natural resource management and environmental status in a country. We have found a systems modelling approach to be the best way of tackling these problems. This approach involves modelling the economy with an emphasis on the processes linking the economy and natural resource use. The models can then be used to simulate the consequences of various assumptions about policy and management changes at macro, meso and micro levels. Models can never give a perfect repreresentation of reality, but may still give useful insights into complex interrelationships.

COMPUTABLE GENERAL EQUILIBRIUM (CGE) MODELS

For studying the economy-wide effects of policy changes on soil degradation and deforestation, and the numerous feedbacks from the resource degradation to the economy, economy-wide models are necessary. For this end, therefore, a computable general equilibrium (CGE) model is being constructed for Tanzania. This model is novel in the way it incorporates soil degradation processes into a CGE framework. Preliminary versions of the model have already been documented in Aune et al. (1994) and Balsvik & Brendemoen (1994). General equilibrium analysis models have several advantages over more partial analysis models. The latter usually trace out only the direct effects of policy changes, while the former also reveal more indirect effects. One example may be the effects of subsidising fertilizers: The subsidies may increase fertiliser use and thus productivity in agriculture. As a result income will increase for the rural population, increasing demand for consumer goods. But the productivity increase may reduce producer prices, relative to other prices and increase demand for agricultural goods. What may seem like a marginal policy change may in fact, through general equilibrium effects, cause profound changes in the overall performance of the economy (Balsvik and Brendemoen 1994). However, frequently the indirect effects will tend to dampen the direct effects of policy changes.

Using CGE models to analyse ecology economy linkages was proposed by Førsund (1985). So far few examples of CGE models incorporating environmental variables can be found. A major obstacle has been the description of the economy ecology links, which are usually assumed to be complex.

CGE models are indeed very demanding of reliable data and a basic understanding of the functional relationships between variables. This is not a trivial problem in countries such as Tanzania, where the capacity for producing economic data is poor and relatively little economic research has been carried out. A spin-off effect of efforts to build CGE models lies in identifying research needs. Areas where data are poor, and relationships where more basic research is needed are highlighted. In the Ecology and

Development programme it has obviously not been possible to fill all the gaps identified. Priority has been given to a better understanding of the relationships between policy changes, land use practices and resource degradation.

Micro level studies of household adjustment to economic changes have been undertaken in several locations in Tanzania. Based on these household studies, resource allocation models have been constructed. Modelling has also been undertaken of the long term development of soil productivity and degradation in Tanzanian farming systems. In order to know the economic cost of soil erosion it is necessary to understand the effects of erosion on soil productivity. This issue has previously not been researched in Tanzania. Trials to quantify these effects represent a major effort under the research programme.

The CGE modelling approach is also being supplemented by several more partial and lower geographical level analyses. A sectoral model for the forestry sector of Tanzania and a model for explaining deforestation processes in Babati District, are both in the early stages. Attempts have also been made to analyse soil managment as an optimal resource depletion problem (Brekke & Iversen in progress).

CONCLUSIONS

We have found the modelling approach a good arena for interdisciplinary collaboration. It is an approach where the languages of economists and natural scientists are not too different from each other, and insights thus can be shared and combined.

This special issue of Norwegian Journal of Agricultural Sciences contains results from ongoing and completed research under the Ecology and Development programme. These papers were presented at a seminar on "Structural Adjustment Policies and the Management of Soil and Forest Resources in Tanzania", held in Morogoro on 2-3 August, 1994. Some papers presenting work in early stages have, however, not been included in this issue.

Is structural adjustment bad for the environment? Tentative conclusions to emerge from our work so far indicate that SAPs can not be said to be entirely good nor entirely bad for the environment. Both positive and negative effects may be seen. The environment can not be treated as one variable. Some environmental problems may be lessened by the effects of adjustment, while others are increased. Although some environmental concerns are exacerbated by SAP policies, the negative effects may to a large extent be dealt with through policies directed at the specific problem. An example of this could be where the SAP increases the profitability of extracting an open access resource. This can effectively be addressed by introducing a tenure regime which restricts access to the resource. This points to the possibility of designing environmental policies that are compatible with the aims of structural adjustment; that can simultaneously promote growth and a more socially optimal management of Tanzania's natural resources – possibly even leading to a sustainable development path. Hopefully, the Ecology and Development research programme can make some contribution towards this end.

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Effect of structural adjustment policies on resource management at peasant household level in Tanzania

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Based on data from a random sample of 298 peasant households in Kilimanjaro and Ruvuma regions of Tanzania, actual and likely impact of structural adjustment programmes on agricultural resource use and environment has been measured. It was found that the area under commercial crops is likely to increase as a result of continued economic liberalisation either at the expense of food crops or through the clearing of more forest lands. The environmental consequences measured by soil mining and deforestation would, however, be more location specific. The current economic reforms are unlikely to be consistent with the conservation of soils and forests and over all sustainable development of agricultural sector.

Key words: Income distribution, resource productivity, soil mining, structural adjustment programmes.

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Mainly as a result of ambitious and increasingly unrealistic development policies, the economic performance of Tanzania started deteriorating in the early 1970s. Rapid expansion of public sector increased the imports so as to outstrip the exports. Real growth lagged behind and the public sector revenue was no more enough to finance the public expenditure in spite of high and increasing foreign aid. The government had to resort to increased domestic borrowing from banking system which fuelled inflation, averaging 25.8 per cent during 1980-90 as compared to 9.6 per cent during 1965-80. Overvaluation of currency and inflation discriminated against exports, most of which were of agricultural origin, and favoured imports of capital goods. Antimarket philosophy and the view held by the government that prices have little or no role in the allocation of economic resources, were responsible for most of the damage done to the economy.

Low and declining real official producer prices reduced production incentives to smallholders which in turn discouraged agricultural production and exports both of food and cash crops. Of the 10 important crops, six experienced real price decreases of more than 30 per cent, while the remaining four experienced real price declines between 19 and 30 per cent within a short time-span of four years from 1969-70 to 1973-74 (Skarstein 1986). The widespread shortages of most basic consumer goods and the lack of transport equipment, fuel and spare parts also limited the incentives to raise agricultural production (EIU, 1993). Expansion in the industrial sector remained extremely low as productivity fell drastically in all the sectors. The government responded to the imbalances and shortages each time with increased controls. The price signals were, thus, prevented from being transmitted through the economy. This resulted in an inefficient production structure. By the year 1979, price control had been extended to 325 product categories (Kiondo 1990). The economic measures consisting of administrative allocation and centrally fixed prices proved counterproductive. The economic agents were forced to make their own adjustments which gave rise to parallel markets.

The failure of the official economy and the crisis of legitimacy of the government necessitated the adoption of structural adjustment reforms (SAPs) in the country. A modest beginning was made with a policy package during the mid seventies (Weaver & Anderson 1981), which provided for major increases in producer food prices, 40 per cent increase in minimum wages, sharp increase in retail prices of basic foods, tax increases, etc. Another serious attempt at internal adjustment was made later when the short lived National Economic Survival Program (NESP) was adopted. It entailed cuts in salaries and social services, on the one hand, and increases in taxes on salaried workers and in the official producer prices on the other. The real beginning of SAPs in Tanzania can, however, be traced to a stand-by facility negotiated with the IMF in September 1980 which broke down after the country failed to meet the conditionalities attached to the loan[1]. The main economic reform programmes in Tanzania can be broadly grouped into the following:

(i). National Agricultural Policy (NAP): Adopted in 1982, NAP was aimed at encouraging private investment by individuals and enterprises, including those of foreign origin, in large scale farming.

(ii). Measures adopted in the 1984-85 Budget: The focus of these measures was on price decontrols and trade liberalisation of imports of consumer, intermediate and capital goods. The official agricultural producer prices were significantly increased and the price controls were decreased from 325 to only 72 goods in 1984 (Kiondo, 1990). The currency was devalued so as to promote exports.

(iii). Economic Recovery Programme (ERP): This was formulated by the government in 1985/86 in co-operation with the World Bank and implemented between 1986-87 and 1988-89. ERP is said to be the most radical policy package since the Arusha Declaration (Lipumba & Mbelle 1990) which aimed at improvements in the official marketing system, more efficient allocation of foreign currency and tight fiscal and monetary policy. Although ERP fell short of its growth targets, it exceeded all the previous adjustment efforts in the scope of its measures and has helped to sustain a recovery since 1986.

(iv). The Economic and Social Action Programme (ESAP or ERP II): This was implemented in 1989-90 to 1991-92 as the successor to the ERP. Market liberalisation measures were gradually extended to achieve the same

[1]Conditionality criteria refer to the macroeconomic policy measures and performance criteria agreed upon with the IMF in a secret document, a letter of intent, signed unilaterally by the government of the client country. These criteria must be fulfilled in order to receive the IMF credit according to the agreed schedule of disbursements (Skarstein, 1991).

macro-economic goals as set under the ERP but greater emphasis was placed on alleviating the social costs of adjustment. Decontrol of prices has been gradual over time and price decontrolled goods were reduced from 72 product categories in 1984 to only two in mid-1991 (World Bank 1991). Liberalisation of the foreign exchange market and banking sector also began in 1992 under this programme. IMF backing for the programme continued after July 1991 with the approval of an enhanced structural adjustment facility credit of SDR 181.9 mn over the period of three years. Thus the process of gradual economic liberalisation has continued without interruption to the present.

The agricultural sector is often prominent during the course of SAPs, both because it is a major productive sector and because it is invariably the object of myriad policy interventions[2]. In Tanzania, where agriculture contributes more than 60 per cent of GDP and employs over 80 per cent of the total work force in the mainland of the country (EIU 1993), no serious attempt in measuring the impact of SAPs on economy can afford to neglect this sector. Most of the agricultural land, which constitutes 5.6 per cent of the total land area of the country, is under small holder cultivation with an average farm size less than two hectares. During the 1980s, about 85 per cent of the total agricultural area was cultivated by hand tools, 10 per cent by ox-ploughs and the remaining five per cent by tractors (Skarstein 1986), a position which is nearly unchanged even today. The low intensity of input use is responsible for the low productivity in this vital sector of economy. Significant changes in prices of agricultural inputs and outputs, and agricultural marketing infrastructure, emphasised under the SAPs, are likely to have far reaching impact on the over all economic performance of the country by affecting the peasant households who are the users and producers of the bulk of agricultural resources and products. It would, therefore, be interesting not only to know the effect of these economic reforms on some vital parameters like changes in cropping pattern, resource productivity and efficiency and income distribution but also their likely environmental implications. Unfortunately no systematic effort has so far been made in this direction. This study of peasant households was, therefore, undertaken in Tanzania to assess the actual or likely impact of SAPs on the cropping patterns, efficiency of agricultural resource use, soil mining, deforestation, etc. The specific objectives of the study were the following:

(1). to study the impact of SAPs on the availability of agricultural inputs and consumer goods to the peasant households,

(2). to analyse the effect of ongoing economic reforms in terms of actual and expected changes in cropping pattern and income distribution,

(3). to estimate the productivity and allocation efficiency of different agricultural resources and discuss their likely environmental implications, and

(4). to develop suitable peasant household models for assessing the impact of price liberalisation on cropping patterns and environmental degradation.

[2]SAPs every where invariably involve a considerable reordering of agricultural policies. In a Word Bank study of 79 structural adjustment loans, institutional reforms in agriculture, changes in input and output prices, and changes in public investment budget for agriculture were conditions respectively in 71, 57 and 47 per cent of them (Gittinger, 1988).

THE STUDY SAMPLE: SIZE AND SELECTION

For the purpose of this study a reasonably large size of the sample of peasant households was selected from two agriculturally important regions in the country, namely, Kilimanjaro and Ruvuma. These regions are not important in respect of the production of food crops only but also for the production of cash crops like coffee and tobacco. Besides, the agricultural input use is relatively more intensive here than in many other parts of the country. The two regions represent typical agricultural resource management conditions in that while soil erosion is relatively more serious in Kilimanjaro region, deforestation may assume importance in Ruvuma region due to cutting of trees for curing of tobacco. This study is, therefore, helpful in identifying changes in cropping patterns, agricultural resource use, soil mining and deforestation, etc., in representative regions of the country as a result of SAPs.

In Kilimanjaro region, the study was located in a single district, namely, Moshi (Rural). In Ruvuma region, however, two districts, namely, Songea (Rural) and Mbinga, representing important tobacco and coffee growing areas respectively, were selected for the purpose. The study sample was then selected by using two-stage random sampling. At first stage, six villages were selected randomly from each region, i.e., six, four and two from Moshi (Rural), Songea (Rural) and

Table 1. Details of the Regions, Districts and Villages and the Number of Farm Households Selected in the Study sample.

Region	Name of the Region/ District	Name of the Selected Village	No. of House-holds
I.	Kilimanjaro/ Moshi (Rural)	1. Singa Chini	27
		2. Singa Juu	25
		3. Otaruni	25
		4. Kyala	25
		5. Msae	25
		6. Rawya	27
Total number of households selected from Kilimanjaro region - Region I			154
II.	Ruvuma/Songea	1. Mgumbashi	20
		2. Namtumbo	25
		3. Litowa	25
		4. Minazinie	24
	Ruvuma/Mbinga	1. Mapera	25
		2. Mpapa	25
Total number of households selected from Ruvuma region - Region II			144
Total number of households selected from both the regions			298

Mbinga districts. At the next stage, the peasant households were selected for in depth study. This was done by randomly selecting about 25 households from each of the 12 villages. Thus a reasonably good proportion of total number of households was selected from the sample villages. Since there are not much variations in the farm size in the two regions, hence no necessity was felt to stratify the farms according to size. In all, 154 and 144 farm households, thus making a total sample of 298, were selected from Kilimanjaro and Ruvuma regions. Details about the study sample are given in Table 1.

THE DATA: REQUIREMENTS AND COLLECTION

The primary data on different aspects of agricultural input use, production and other related variables were collected by interviewing the sample households on a specially prepared and pre-tested questionnaire. In majority of the cases, head of the household was interviewed. The survey was conducted with the help of research staff of the Department of Rural Economy, Sokoine University of Agriculture, Morogoro, Tanzania during the period January 1993 to October 1993. Since the most recent agricultural year at the time of economic survey, i.e., 1992-93, happened to be an abnormal year, hence the input-output information referred to the agricultural year 1991-92. Since the sample households in the study areas did not maintain regular farm records, hence recall method was used for obtaining the necessary data. This limitation of the study, therefore, needs to be kept in mind while interpreting the results.

ECONOMIC MODELS

Basically three methods are employed for analysing the impact of SAPs. First, "before" and "after" situations are compared to bring out the impact of SAPs. Secondly, farmers' likely response to the SAPs, based on their expectations, is analysed. Finally, modelling approaches, using production functions and linear programming, are used to measure the productivity and allocation efficiency in agricultural resource use on the peasant households during the course of SAPs.

Though a number of production function forms, such as, linear, Cobb-Douglas, transcendental and translog were tried, but for economic and statistical reasons the final choice rested with the single equation Cobb-Douglas function which was estimated by the ordinary least squares method for important crops and aggregate crop production. The specifications of the fitted production function are given below:

$$\ln Y = \ln b_0 + dD + b_1 \ln(\text{Land}) + b_2 \ln(\text{Working Capital}) + b_3 \ln(\text{Human Labour}),$$

where Y measures the output in kilograms for a specific crop or value of all crops for the aggregate production function, "$\ln b_0$" is the intercept term, D is the region dummy variable taking a value of "0" for Kilimanjaro and "1" for Ruvuma, and b_1, b_2, b_3 are the elasticity of production coefficients with respect to the explanatory variables land, working capital and human labour respectively.

Linear programming models for representative households, were used as a supplementary approach for measuring the impact of SAPs. These models sought to maximise the gross margins subject to a number of constraints, goals and accounting equations relevant to farmers' decisions. The model included all the important production activities, like crops, milk and meat; input purchase, consumption and selling of products, common in the study areas. Given the short-run nature of the analysis, area under coffee, bananas, yams, etc., and the number of milch cows and that of goats in Kilimanjaro region, and only the number of goats in Ruvuma region[3] were kept fixed. The impact of SAPs was sought to be measured by using two sets of prices, i.e., prevalent during the years 1991-92 (the base scenario) and 1993-94[4] (economic policy scenario representing higher degree of economic liberalisation). The likely changes in incomes of the householdds, the cropping pattern and reguirements of wood for tobacco curing and nutrient depletion[5], as a proxy to measuring the impact on forests and soils, were estimated. The approximate effect on risk, measured by total absolute deviation (Hazell, 1971), and labour use variation during the period of 12 months (Sankhayan et al. 1988) were also obtained. Validation of the model by comparing the simulated and survey data for the production pattern, brought out that the model was quite successful in replicating the observed production pattern.

STRUCTURAL ADJUSTMENT PROGRAMMES AND THE SAMPLE HOUSEHOLDS

In this section the extent of awareness of the sample households about the SAPs, and the actual or likely effect of the economic reforms on the availability of farm inputs and consumer goods, changes in the production of food and cash crops and resulting changes in income distribution are discussed.

Awareness about the SAPs

While many people in and around the urban centres may be aware of the economic reforms being undertaken in the country from time to time, the residents in the remote rural areas are expected to be relatively less aware mainly due to poorer communication facilities available to them. The sample households were asked as to whether they were aware about the economic reforms in the country and if so, when did they first hear about them? The position in this respect in the two regions over time is presented in Table 2.

Up to the time of survey in 1993, only 58.05 per cent of the total sample households showed some awareness of the economic reforms being adopted in the country. Thus more than 40 per cent of the farm households knew nothing about the SAPs. Of the total number of households showing awareness about the structural adjustment programmes in each

[3] The household modelling in Ruvuma region was confined only to Songea (Rural) district where coffee is not grown.

[4] Prices prevalent during the year 1993-94 represented greater degree of economic liberalisations as compared to those during 1991-92. It was, therefore, used as a basis to measure the impact of economic reforms, under the assumption that the household follows a normative behaviour pattern.

[5] The nutrient balance in this study is measured in terms of N, P and K only and the same is based on a procedure outlined in Stoorvogel & Smaling (1990).

Table 2. Sample households showing awareness about the economic reforms in two regions of Tanzania.

Year when first heard about the economic reforms	Number of sample households showing awareness about the economic reforms in		
	Kilimanjaro Region	Ruvuma Region	Total
1980 to 1985	12 (14.29)	7 (7.87)	19 (10.98)
1986 to 1990	33 (39.28)	24 (26.97)	57 (32.95)
1991	22 (26.19)	24 (26.97)	46 (26.59)
1992	15 (17.86)	28 (31.46)	43 (24.86)
1993	2 (2.38)	6 (6.74)	8 (4.62)
Total number of households	84 (100.00)	89 (100.00)	173 (100.00)

Note: Figures in the brackets are the percentages to the total number of farmers showing awareness about the economic reforms in the country.

region, 53.57 and 34.84 per cent had come to know about them up to the year 1990 in Kilimanjaro and Ruvuma regions respectively. Thus in the early stages greater proportion of sample households showed awareness with the economic reforms in Kilimanjaro region than in Ruvuma region. This position was, however, reversed by the year 1993. With the passage of time more and more farm households were getting familiar with the SAPs in both the regions.

Availability of Farm Inputs and Consumer Goods

Respondent households were asked questions regarding the position of availability of agricultural inputs and consumer goods during the year of survey in 1993 as compared to that 8-10 years ago, representing a situation before the introduction of structural adjustment reforms. The response of the sample farm households in this regard is analysed in Table 3.

Table 3. Situation in respect of availability of farm inputs and consumer goods on the sample households in Tanzania as a result of adoption of SAPs in the country.

Whether inputs/ consumer goods available	Farm Inputs		Consumer Goods	
	Kilimanjaro Region	Ruvuma Region	Kilimanjaro Region	Ruvuma Region
Available	66	32	97	75
	(66.7)	(43.8)	(100.0)	(100.0)
Not available	33	41	..	..
	(33.3)	(56.2)	..	..
Total	99	73	97	75
	(100.0)	(100.0)	(100.0)	(100.0)

Note: Figures in the brackets are the percentages to the total number of respondent households in the region.

This study brought out that the position in respect of availability of consumer goods had greatly improved during 1993 as compared to 8-10 years ago in the rural areas. Sample households who responded, reported the availability of all the necessary consumer goods in the rural areas during the recent times.

The impact of economic liberalisation in the country, therefore, is quite visible in regard to the removal of hardships of the peasant households by abolishing the scarcity of essential consumer goods and thus the operation of parallel markets even in the remote rural areas. This has in turn resulted in valuable saving of time and effort for the peasant households who are now able to concentrate more on farming. It is likely to contribute indirectly towards raising agricultural production, income and quality of life of the rural masses.

In contrast to the significant improvements in respect of the availability of consumer goods, the availability of farm inputs, like fertilisers, seeds, insecticides, tools, etc., is still far from satisfactory. Quite a few farm households (33.3 and 56.2 per cent in Kilimanjaro and Ruvuma regions) reported that the availability of agricultural inputs in their villages had yet not improved during the recent times as compared to that 8-10 years ago.

The distinct position in respect of the availability of consumer goods vis-a-vis the farm inputs is explained by the fact that privatisation in the latter market has yet not taken place to a desired extent in rural Tanzania. Though some private traders were now reported to have entered into the marketing of some agricultural inputs, like fertilisers, in Kilimanjaro region, they were almost absent in Ruvuma region. Probably the low density of population, poor transport facilities, longer distance from the town centre, etc., were responsible for the observed behaviour in Ruvuma. The position is expected to improve as the government loosens its grip on agricultural marketing in the process of liberalisation in the future.

Changes in Cropping Pattern in Response to SAPs

More than 80 per cent of the sample farmers were reported to have grown maize during the year 1991-92 in the two regions. Finger millets and cassava cultivation (only in Ruvuma region) is still practised by some farmers mainly because of the ability of these crops to withstand draught conditions and thus provide food security. Since profit maximisation is not the only objective of the peasant households, therefore, these crops find place in the cropping pattern irrespective of their low profitability. Banana growing is very popular in Kilimanjaro region, where it is grown in the coffee plantation and constitutes an important staple food of the people. Other food crops are of relatively less importance. Of late, paddy and wheat cultivation has been gaining importance in the cropping pattern due to higher profitability. These crops are mainly grown for the market.

Coffee was grown by all the sample households in Kilimanjaro but only by about one third of the households in Ruvuma region, all of whom were confined to Mbinga district. The fire cured tobacco is an important cash crop in Songea district of Ruvuma region. About 50 per cent of the sample households were observed to have grown this crop in the region. A few farmers also grew a number of other minor crops in both the regions. More than 80 per cent of the sample households were engaged in growing three or more crops on their farms during a given year. A precise idea about the changing cropping pattern during the recent past can be had from Table 4 which presents the average cropped area under different crops over a period of three years, i.e., 1989-90 to 1991-92.

There appeared no definite shift in area under different food and cash crops in any of the two regions during this period. The time span is perhaps too short to enable us to draw a definite conclusion. One would perhaps have to wait for a few more years before the likely effects of structural adjustment programmes start becoming clear on the cropping patterns in Tanzania. Area under a perennial crop like coffee certainly needs longer time to respond to macro-economic reforms. The mandatory ban on the uprooting of coffee plantation still continues in the country which does not give full freedom to the farmers up to this time to respond fully to the economic signals.

Production of Cash and Food Crops[6] in the Future – Farmers' Likely Response

As already discussed in the forgoing section, because of low intensity of implementation of SAPs and inadequacy of the sufficiently long time span up to the conduct of the economic survey, it is difficult to produce conclusive evidence in regard to changes in respect of production of food and cash crops. The best way, therefore, was to ask the peasant households about their expectations in

Table 4. Average Area under different crops on the Sample Households during 1989-90 to 1991-92 in two Regions of Tanzania.

(Hectares)

Sr. No	Crops	Kilimanjaro Region			Ruvuma Region		
		1989-90	1990-91	1991-92	1989-90	1990-91	1991-92
1	Maize	0.44	0.45	0.46	0.95	1.25	1.25
2	Paddy	0.00	0.00	0.02	0.13	0.13	0.17
3	Wheat	0.00	0.00	0.00	0.08	0.09	0.09
4	Finger millets	0.02	0.01	0.02	0.03	0.08	0.09
5	Beans	0.36	0.35	0.39	0.33	0.45	0.55
6	Cowpeas	0.00	0.00	0.00	0.01	0.01	0.01
7	Coffee*	0.63	0.65	0.66	1.34	1.35	1.33
8	Tobacco*	0.00	0.00	0.00	0.35	0.42	0.42
9	Sugarcane	0.00	0.00	0.00	0.00	0.01	0.01
10	Cassava	0.00	0.00	0.00	0.17	0.20	0.26
11	Banana	0.63	0.65	0.66	0.05	0.04	0.04
12	Sunflower	0.04	0.06	0.08	0.02	0.0.02	0.03
13	Groundnut	0.01	0.01	0.00	0.01	0.02	0.02
14	Sesamum	0.00	0.00	0.00	0.02	0.05	0.05

* Averages for coffee and tobacco in Ruvuma region are based on 50 and 94 observations, the number of sample households in Songea and Mbinga districts respectively.

[6] The distinction between food and cash crops is quite arbitrary. In this study, we have followed the traditional classification. Under such a classification, a crop like maize, for example, is treated as a food crop even though it may also be sold in the market for obtaining cash income.

response to the ongoing economic reforms with their important components of price liberalisation and removal of input subsidies. Data on the likely response of the sample households is presented in Table 5.

Of all the farmers who responded to this query in the survey, greater proportion felt that they would respond by increasing production of food crops in the future than those who intended to respond by increasing the production of cash crops, if the existing economic and technical regimes continued.

In both the regions combined, 65.7 per cent of the sample households expected to respond by increasing the production of food crops as against 47.3 per cent who intended to increase the production of cash crops. Thus, a greater proportion of households expected the production of cash crops either to decrease or to remain unchanged as compared to that of food crops. The expectation patterns in the two regions were quite different. Majority of respondents in Kilimanjaro region expected to react to the economic reforms by increasing the production of food crops at the expense of cash crops because of strong constraint on the expansion of land area. In Ruvuma region, however, a greater proportion of farmers expected to respond by increasing the production of both the types of crops through expansion of area. There are distinct possibilities of expansion of cultivated area by clearing the adjoining forests in this region.

The results in terms of actual changes in total area and production of food and cash crops may be different than those shown by this analysis if the increase in cultivated area is not the same for all the farm households. This is probably more likely to be the case.

Table 5. Likely response of peasant farmers to the structural adjustment programmes in respect of production of food and cash crops in the two regions of Tanzania.

Region/ Crop	Farmers' response: Production will			Total number of respondents
	Increase	Decrease	Remain same	
Kilimanjaro				
Food crops	59 (61.4)	33 (34.4)	4 (4.2)	96 (100.0)
Cash crops	33 (33.6)	62 (63.3)	3 (3.1)	98 (100.0)
Ruvuma				
Food crops	52 (71.2)	11 (15.1)	10 (13.7)	73 (100.0)
Cash crops	47 (66.2)	15 (21.1)	9 (12.7)	71 (100.0)
Both the regions				
Food crops	111 (65.7)	44 (26.0)	14 (8.3)	169 (100.0)
Cash crops	80 (47.3)	77 (45.6)	12 (7.1)	169 (100.0)

Note: Figures in the brackets are the percentages to the total number of respondents in the respective region.

Changes in Income Distribution

Rise in agricultural prices, a common feature of most SAPs, is likely to result in negative economic welfare on the very poor, particularly the families with very little or no land. Purely in terms of producer incomes, the price driven effects of the SAPs may be redistributive in favour of the more commercial farmers and run against the more traditional, poorer producers (Norton, 1987). The reduction in input subsidies may, however, diminish this tendency somewhat. To the extent that the commercial farmers are more influential politically, the SAPs may affect them adversely. It is, therefore, difficult to make generalisations about the income distributional effects of structural adjustment programmes among the rural households. Empirical investigations may, therefore, have to be made to document the distributional expriences in each country.

Income for each sample household for the year 1991-92 was found out by summing up the value of different farm products and also the non-farm income, if any. After correcting for the family size, the size distribution of income was measured by working out the quintiles, Gini coefficient and quintile ratios. These estimates were then compared with those given in Jazairy, Alamgir and Panuccio (1992), who based their estimates on expenditures and not on incomes, for the years 1969 and 1970-75 for rural areas in Tanzania (Table 6). Such comparisons may not, therefore, be strictly valid, yet they are useful in providing a direction of change[7].

Based on the estimates of quantiles or quantile ratios, there were indications of worsening of income distribution in rural

Table 6. Size Distribution of Income in Two Regions of Tanzania during the year 1991-92 compared with that of the country during 1969 and 1970-75.

Quintiles/Quintile ratio/Gini Coefficient	Kilimanjaro Region 1991-92	Ruvuma Region 1991-92	Both the Regions 1991-92	Tanzania* 1969	Tanzania* 1970-75
Lowest 20 %	1.82 (5.1)	6.5 (8.8)	2.6	5.8	6.0
Second Quintile	6.01 (9.8)	11.4 (13.4)	8.9	10.2	10.0
Third quintile	13.05 (15.0)	16.6 (16.7)	15.3	13.9	-
Fourth quintile	22.51 (21.9)	22.4 (22.1)	23.3	19.7	34.0#
Highest 20 %	56.62 (48.2)	43.1 (39.0)	49.9	50.4	50.0
Quintile ratio	31.11 (9.4)	6.6 (4.4)	18.8	8.7	8.3
Gini ratio	0.55 (0.42)	0.36 (0.30)	0.47	0.39	0.45

* Jazairy, I., Alamgir, M. and Panuccio, T. (1992).

Third and fourth quintiles combined.

Note: Figures in the brackets relate to the size distribution of cultivated area.

[7] It should also be pointed out that income distribution is likely to change over time with or without adjustment. Unsustainability of disequilibrium suggests that some adjustments are inevitable which will change the distribution of income (Gaiha 1991). "Before" and "after" comparisons may, therefore, often be misleading. What might be more appropriate in this context is to compare the income distributions under different ad adjustments (Johnson & Salop, 1980)

Tanzania over the period 1970-75 to 1991-92. The magnitudes of Gini ratios were, however, not much different during the two periods.

Though all the changes in income distribution may not be attributable to SAPs, yet there is no denying the fact that radical economic reforms during this period were most important in affecting it. Thus, the SAPs are likely to have rendered the rural poor still poorer. The effect appears to be more severe in Kilimanjaro region than in Ruvuma region.

The rural income was relatively better distributed in Ruvuma region than in Kilimanjaro region during the year of study. Since land is the most important of all the agricultural inputs on the peasant farms, its distribution may be responsible for the observed behaviour of income distribution within and between the regions. In order to examine this explanation, therefore, the distribution pattern of cultivated area was also worked out. It was found that the distribution of land area followed the same pattern as that for income, i.e., like income, land area was also better distributed in Ruvuma region than in Kilimanjaro region. Thus, the better distribution of income in Ruvuma can be mainly attributed to better distribution of land area as compared to that in Kilimanjaro region.

PRODUCTION FUNCTION ESTIMATES, RESOURCE PRODUCTIVITY AND ALLOCATION EFFICIENCY

The estimates of Cobb-Douglas production functions for different crops and aggregate production are presented in Table 7.

The values of R^2, the coefficient of multiple determination, were reasonably high for the fitted production functions. The fit to the data could have been further improved had some more important explanatory variables, like the age of the coffee plantation, level of management of the farmers, etc., were included in the regression equations. The F-values indicate that the hypothesis that all coefficients other than b_0 are zeros should be rejected. The coefficients of the dummy variable for different production functions indicated significant differences in technical efficiency in the production of maize, coffee and aggregate crop production in the two regions.

The returns to scale, given by $\sum b_i$, are found to be decreasing for maize and coffee, and increasing for tobacco but were almost constant for the aggregate crop production. Thus it appears likely that the production of tobacco can be more than doubled just by simultaneously doubling the use of agricultural inputs.

In order to measure the productivity of different agricultural resources, marginal value products were worked out at their respective geometric mean levels (Table 8). The marginal value product of land was higher for coffee than for maize in both the regions. While the difference was minor in Kilimanjaro, it was quite marked in Ruvuma region. The marginal value product of working capital was higher for coffee than for maize in Kilimanjaro region. In Ruvuma region, the highest marginal value product of working capital was recorded for tobacco, followed by that for coffee and maize. The marginal products of land, working capital and human labour, as obtained from the aggregate production function, were also higher in Ruvuma than in Kilimanjaro. Farmers who rented in some land from the co-operative societies incharge of the nationalised coffee plantations for cultivating maize in Kili-

Table 7. Estimates of Cobb-Douglas Production Functions for Important Crops and for Aggregate Crop Production in Tanzania.

Production function /Crop	Estimate of constant ($\ln b_0$)	Estimates of Regression Coefficients in respect of: Regional Dummy# (d)	Land area (b_1)	Working capital (b_2)	Human labour (b_3)	d.f.	R^2 (Adju-sted)	SE_y
Maize	6.0538 (0.1223)	0.68148 (0.11300)	0.85836 (0.07462)	0.06551 (0.01300)		235	0.6676	0.6760
Coffee	3.99500 (0.2082)	1.21450 (0.16660)	0.91185 (0.09990)	0.07799 (0.02550)		174	0.6318	0.7992
Tobacco	2.1017 (0.6957)	-	0.81399 (0.16900)	0.05005[NS] (0.03404)	0.52252 (0.1227)	67	0.6054	0.6228
Aggregate Prod. Function*	8.7942 (0.2101)	0.46761 (0.11180)	0.72671 (0.07768	0.13582 (0.02278)	0.04279 (0.01861)	293	0.5274	0.7874

NS: Not significantly different from zero at a probability level ≥ 95 per cent. All other coefficients are significantly different from zero at a probability level ≥ 95 per cent. SE_y stands for standard error of the estimate.

\# Regional dummy variable took a value of 0 for Kilimanjaro and 1 for Ruvuma region.

* The aggregate output was measured in TSh.

Notes:

1. Standard errors of the estimated parameters are given in the parentheses.
2. Land was measured in hectares, and human labour in man days for tobacco and in man years for the aggregate production function.
3. Two tail test applies to the coefficients of the dummy variable; one-tail test to all other variables.

manjaro region were reported to have paid about Tsh. 25,000 per hectare per annum during the year of study. In addition to this, some amount had also to be paid illegally. Thus, estimate of about Tsh 44,000 (at 1991 prices) for the marginal value product of land appeared quite reasonable which could perhaps be used as a basis by the co-operative societies for charging rent on land in this area.

On the basis of the differences in marginal value products of land, it appears likely that the rational optimising behaviour on the part of farm households requires them to shift this resource from maize to coffee in Kilimanjaro and to coffee in Mbinga district and to tobacco in Songea district of Ruvuma region. But since maize is grown entirely on different lands, the low lands, in Kilimanjaro region which are not suitable for coffee cultivation, hence the shift of area from maize to coffee is not possible. In case of working capital, shift needs to be made in favour of coffee from maize in Kilimanjaro and from maize to coffee in Mbinga district and to tobacco in other parts of Ruvuma region. Thus if the pre-

Table 8. Geometric Mean Levels (GM) and Marginal Value Products (MVP[8]) of Variables used in production functions of Different Crops in Kilimanjaro and Ruvuma Regions of Tanzania.

Production Function for	Region	GM/ MVP	Output* (Kg/TSh)	Land (Hectares)	Working Capital (TSh)	Human Labour
Maize	Kilimanjaro	GM	416.27	0.40426	2699.82	-
	(101)#	MVP	-	44193	0.5050	
	Ruvuma	GM	1770.36	1.22291	8883.09	-
	(138)	MVP†	-	41416	0.4351	
Coffee	Kilimanjaro	GM	140.94	0.41813	2471.89	-
	(136)	MVP	-	76840	1.1116	
	Ruvuma	GM	1084.05	1.16349	22207.60	-
	(42)	MVP	-	101950	0.5336	-
Tobacco	Ruvuma	GM	268.25	0.50420	2988.32	264.87
	(71)	MVP	-	77952	0.8086@	95.25
Aggregate	Kilimanjaro	GM	63453	1.43594	4254.70	3.99807
	(154)	MVP	-	32113	2.0256	679
	Ruvuma	GM	190075	3.04610	11427.30	3.31991
	(144)	MVP	-	46670	2.2592	2450

Number of observations on which the production function is based.

* Output in all the production functions is measured in kilograms except that in the aggregate production function where the same is measured in TSh (Tanzanian shillings).

† Marginal value product (MVP) is measured in Tanzanian shillings.

@ Calculated from regression coefficient not statistically significantly different from zero.

sent price and technical regimes continue and the farmers are assumed to strive for optimisation of scarce resources, there appears likelihood of intensification of input use for the cash crops like coffee and tobacco at the cost of a food crop like maize, and perhaps some other food crops not included here for production function analysis. Thus based on normative analysis, the SAPs seem to favour the production of cash crops against the food crops. This is perhaps not a very surprising finding as the economic reforms invariably seek to achieve such an objective.

[8] Per kilogram prices in Kilimanjaro and Ruvuma regions used for estimation were Tsh 50 and 33.33 for maize, Tsh 250 and 120 for coffee, and Tsh 180 for tobacco, and the same related to the year 1991-92.

Table 9. Linear Programming Model[9] Results for 1991-92 and 1993-94 Scenarios in Moshi District (Kilimanjaro Region) and Songea District (Ruvuma Region) of Tanzania.

Region/Objective function/ Variable	Units	1991-92 Price Scenario	Liberalised Price Scenario
Kilimanjaro Region			
Crops	Ha (%)		
Coffee+Banana+Yams	"	0.66(37.29)	0.66(37.29)
Beans - Low land (short rains)	"	0.14 (07.91)	0.14 (07.91)
Maize - Low land (Long rains)	"	0.97(54.80)	0.97(54.80)
Total cropped area	"	1.77 (100.00)	1.77 (100.00)
Nutrient Balance*	Kg/Ha		
N	"	11.89	11.89
P	"	-3.39	-3.39
K	"	-27.77	-27.77
N+P+K	"	-19.27	-19.27
Level of Risk**	TSh	-	Unchanged
Labour use variations**	Day	-	Unchanged
Value of objective function			
Gross margins++	TSh	224726	431247
Ruvuma Region			
Crops	Ha		
Maize+Beans mixture	"	1.09 (39.07)	0.76 (27.24)
Paddy	"	0.37 (13.26)	0.37 (13.26)
Maize+Paddy mixture	"	0.40 (14.34)	0.00 (0.00)
Cassava	"	0.20 (7.17)	0.20 (07.17)
Tobacco	"	0.73 (26.16)	1.46(52.33)
Total cropped area	"	2.79 (100.00)	2.79 (100.00)
Nutrient Balance*	Kg/Ha		
N	"	16.26	8.41
P	"	-14.55	-14.28
K	"	-37.41	-49.20
N+P+K	"	-35.70	-55.07
Wood Requirements for+			
Tobacco curing	m^3	3.617	7.22
Level of Risk	TSh	-	Increased
Labour use variations	Days	-	Increased
Value of Objective function			
Gross margins	TSh	244196	429965

* The nutrient balance is calculated by using the procedure outlined by Stoorvogel and Smaling (1990). The figures for addition of the nutrients by deposition, biological N fixation, sedimentation and through the effect of fallowing of land, and that for the depletion through leaching, gaseous losses, and erosion as given in this study for the year 1983 are used for making the calculations of nutrient balance.

** The level of risk was represented by total absolute deviation in gross returns(Hazell, 1971) and labour use deviation over the twelve months was also incorporated in the model by using same methodology (Sankhayan, et al 1988).

\+ Estimates of wood requirements were based on the common norm of 5 m^3 of wood for curing the produce of tobacco from one hectare.

++ Gross margins on an average resource situation farm in Kilimanjaro region are not based only on crop husbandry but also on fixed activities of two dairy cows and two goats. Optimum farm plans in Songea district only incorporated two goats as the fixed activity.

[9] Additional data required for running such models were collected from a smaller sub-sample of the farm households separately at a later stage.

The impact of such changes in cropping pattern on soils and forests is, therefore, likely to be location specific. There would be a tendency towards increased soil mining and deforestation in Ruvuma region but the conditions in Kilimanjaro may, by and large, remain unchanged.

LINEAR PROGRAMMING HOUSEHOLD MODELS: IMPACT OF ECONOMIC LIBERALISATION

The results of "liberalised price scenario", based on the 1993-94 prices and representing the effect of SAPs, are compared with those for the "1991-92 price scenario" in Table 9. In Moshi district of Kilimanjaro region, economic liberalisation only led to increased incomes (not corrected for price rise), and left the cropping mix unchanged. Since the techniques of production did not change, hence the nutrient depletion also remained constant at +11.89, -3.39 and -27.77 kg per hectare for N, P and K respectively. This is understandable as the study area in the region has very limited options to make changes either in cropping mix or in the techniques of production in response to price variations in the short run.

Unlike in Moshi district, the increased farm incomes were accompanied by some changes in the cropping pattern in Songea district as a result of economic liberalisation represented by the level of 1993-94 prices as compared to those of 1991-92. The model highlighted the possibilities of increasing area under a commercial crop like tobacco in response to price signals even in the short run. The area under tobacco increased at the cost of maize+paddy mixture. Such a behaviour on the part of farm households is, however, likely to result not only in increased depletion of soil nutrients but may also enhance the rate of deforestation due to increased demand for fuel wood for tobacco curing. The effects are likely to be much more severe as the product prices get closer to their international levels[10] as a result of the adoption of SAPs. Similar results were obtained even when the problem was solved as a multi-objective linear programming model with maximisation of income and minimisation of risk and human labour use variations over the planning period of 12 months. Due to incorporation of dairy enterprise in the farm plans in Kilimanjaro region, the gross margins from the optimum plans were quite close to that in Ruvuma region even with a much smaller farm size in the former case.

Thus the findings from linear programming household models in the two regions supported the conclusions arrived at earlier by using production function approach about the likely impact of economic liberalisation on cropping pattern, soils and forests.

CONCLUSIONS

Based on the findings of this study of peasant households in two regions of Tanzania, there is sufficient evidence of significant improvements in respect of the availability of consumer goods in the rural areas in Tanzania as a result of SAPs. The position in respect of farm inputs is still far from satisfactory as the government is not ready to quickly loosen its grip on the agricultural marketing. There is no conclusive evidence as yet about any shift in cropping pattern as a result of economic reforms. Even the expected behaviour on

[10] Prices of commercial crops like coffee and tobacco in 1993-94 were still quite low as compared to their international levels.

the part of peasant households gives no definite evidence in this regard. The worsening size distribution of income over time is indicative of the fact that the economic policies may have been more harsh to the rural poor.

Assuming a normative economic behaviour on the part of peasant households, there is likelihood of increase in the production of commercial crops like coffee and tobacco in the future, both through expansion of area and intensive use of inputs, provided the present techno-economic regime continues. The expansion of area may be achieved either through area shifts from crops like maize and other food crops or through clearing of new lands or partly by both the methods. In Kilimanjaro region, particularly in the upper belt, there is no evidence either of worsening of soil mining or that of deforestation as a result of economic liberalisation. Contrary to this, increased area under a crop like tobacco in Songea district in response to economic liberalisation, may lead not only to its high fuel requirements for curing and hence to increased deforestation and loss of vegetative cover, but also result in increased soil mining. Thus, the environmental consequences are more likely to be location specific. While the level of negative environmental changes may remain unchanged in Kilimanjaro region, the same may get accentuated in Songea district of Ruvuma region where tobacco is an important cash crop on the peasant farms.

The most important policy implication of this study, therefore, is that the economic liberalisation programme currently being undertaken in Tanzania may not be consistent with the conservation of soils and forests and overall sustainable development of agricultural sector. It would, therefore, be a good idea to continuously keep on monitoring the impact of SAPs by conducting similar studies with broader geographical coverage from time to time in the future. This will go a long way to help formulating, revising and implementing the SAPs consistent with the over all goals of social justice and sustainable development.

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The influence of structural adjustment programmes (SAPs) on forest industry in Tanzania

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Under Structural Adjustment programmes (SAPs) in Tanzania, the forestry industries have been greatly affected. Partial analysis of the data so far collected indicates most of the forest industries to be utilizing about 50% or less of their installed capacity. Examples of such industries are the Fibreboard Africa Limited, Kibo Pulp and Paper Industry, Tembo Chipboard Company, Kilimanjaro Timber Utilization sawmill and most other sawmills. The major reason for this situation, among others, is the lack of capital (local and foreign exchange). Some of these industries have been advertized for either outright purchase or a joint venture. This arrangement is intended to improve efficiency. For the purpose of this study, Tanzania has been divided into five zones covering a total of seven regions. For exports and imports, each region is treated as a zone. About 15 forest products were chosen for consideration. Each region and forest industries in the region under the study will be visited to collect data. Detailed data analysis will be conducted using a non-linear partial equilibrium model.

Key words: Forest industry, non-linear partial equilibrium models, structural adjustment programmes.

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Sustainable development is not a fixed state of harmony, but rather a dynamic process of change over time in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional changes are made as consistent as possible with the future as well as present needs. In order to achieve sustainability there must be conscious awareness of the importance of proper utilization of resources (Jerve 1990).

From the welfare maximization point of view, sustainable development may be defined as the maximizing the net benefits of economic development subject to maintaining the services and quality of natural resources over time (Pearce & Turner 1990).

It is against this background that in 1992 a research programme code-named "Ecology and Development" was established at the Centre for Sustainable Development (CSD), Agricultural University of Norway. The main task of the programme is to analyse the impact of structural adjustment programmes (SAPs) on the management of soil and forest resources in southern and eastern Africa, viz, Tanzania, Zambia and Ethiopia.

This text represents one of the many projects under the CSD, perhaps the only one addressing forest industries in Tanzania. The main objective of this paper is to examine the influence of structural adjustment programmes on the development of forest industries.

THE CONCEPT, APPLICATION AND PRACTICAL IMPLICATIONS OF STRUCTURAL ADJUSTMENT PROGRAMMES

The concept of structural adjustment programmes (SAPs)

Structural adjustment programmes (SAPs) were introduced in the developing countries by international monetary institutions, notably the International Monetary Fund (IMF) and the World Bank, with the objective of remedying bad economic performance. The underlying premise of adjustment programmes is that the economies of most developing countries are not only affected by external shocks, such as oil crisis in 1973-74, but also by inappropriate policies and mismanagement. Therefore, the SAPs were introduced as a means of structuring the political economy of these countries.

At face value, the IMF and the World Bank introduced two variations of economic reforms. The IMF introduced the "stabilization programmes" which are aimed at reducing external imbalances and internal disequilibria in the short-term by policies directed toward bringing the economy closer to full capacity and consumption closer to available means (Sarris 1990). The World Bank introduced the "structural adjustment programmes" aimed at influencing the full employment equilibrium itself by policies directed at raising the efficiency and growth. In as much as a multitude of instruments are involved in restructuring a given political economy, the two policies are necessarily taken jointly under the umbrella of the so-called "Structural Adjustment Loans, SALs or simply Structural Adjustment Programmes, SAPs". The latter view will apply to this paper. In essence, therefore, no explicit distinction is made between the two "doctrines" rather we shall talk of a combined package as the two approaches were implemented jointly in the Tanzanian case to remedy some of the economic failures discussed in the next section.

Structural adjustments concern both trade and fiscal/financial policies. More specifically SAPs advocate, among other things, reducing government spending, exchange rate reforms, export promotion, import liberalization and institutional reforms. Most of these measures have bearing on the development and management of forest resources. For instance reducing government spending may involve removal of subsidies and minimizing "overhead costs". Such a measure could have the effect of reducing financial support for the management of forest resources, most of which are publicly owned. This results in land degradation and environmental pollution because there will be no funds to finance control measures. Exchange reforms, viz, devaluation, will mean an increase in the domestic price of tradeable forest products when valued at the border prices. This may in effect stimulate increased production of forest tradeable products so long as the processing capacity allows. Import liberalization increases the availability of internationally traded forest goods, such as paper and pulp, which will compete with locally produced ones. The possible effect is that local industries must improve quality in order to make their products competitive in the market. These examples serve to illustrate possible effects of SAPs on forest industry development. A detailed treatment of the subject is, nevertheless, beyond the scope of this paper.

The main criticism of SAPs is that the international monetary institutions tend to apply uniform or standard measures to all developing countries regardless of the inherent variations in socio-economic development. This resulted into failure of SAPs in most recipient countries. And where improvements have been registered, the World Bank contend that, it is due to the high success rate in the countries respecting conditions of adjustment loans. But such countries are not many as the conditionalities are more often fairly stringent. A detailed account of the possible impacts of SAPs on the environment and agriculture is given by Reed (1992) and Sarris (1990). Sarris (1990) includes also a conceptual framework for tracking the effects of SAPs, especially in relation to agricultural development.

Aspects of government failures leading to SAPs

The Arusha Declaration and public policy

In 1967 Tanzania adopted the Arusha Declaration, a blue-print of Tanzania's aspirations towards becoming a socialist state. The adoption of the declaration emphasized that land is a public property, decreed public ownership of the means of production and discouraged private ownership of property. In other words private property rights were not only discouraged but in some cases denied. This decree had a negative impact on the production sector.

The Ujamaa (socialist) policy of state controlled production discriminated private initiative with the consequence of stagnation in production. It curtailed the improvement of the existing land use systems as well as the absorption of new technologies. Also individuals feared to invest more in economic ventures due to fear of confiscation by the "socialist" government.

Pricing policy

Market prices are normally the ones used to evaluate economic performance to the extent that they reflect the willingness of consumers to pay for one marginal unit of the goods more of what they actually buy and the producers' marginal cost of producing one unit more of the good. The main utility of market pricing is that, prices send correct signals to both producers and the consumers (Sarris 1990).

In Tanzania, like in most developing countries, there was tendency of high degree of rationing and price controls (ibid). Thus there existed strong parallel markets, which were conventionally referred to as "black markets" but not necessarily illegal, with their prices different from the official or controlled ones that reflected more accurately the supply and the demand conditions (Sarris 1990; Gibbon, et. al. 1992). The parallel market approximated the real market situation characterized by competitive market forces.

Most often controlled or official prices were significantly lower than the prices offered by the parallel market while at the same time the government tried to control both the producer and the consumer prices. By offering low prices to commercial goods, however, the government took away an economic incentive for efficient production.

Foreign exchange policy

Tanzania's policy on foreign exchange has been that of rationing and overvaluation of the domestic currency, the Tanzanian Shilling, which "grossly distort the border prices expressed in domestic currency" (Somogyi 1989). The relationship between price levels and exchange rates can be illustrated using the purchasing power parity (PPP) doctrine (Mbelle 1988). There are two propositions in the theory. The first one known as the absolute version of PPP states that "the exchange rate between two currencies will be determined by the ratio of the price levels of the two countries" (ibid). That is,

$$r = P/P^* \qquad [1]$$

where

r	=	exchange rate
P	=	domestic price level
P*	=	price level of foreign country

The second proposition is the relative version of PPP which states that a percentage change in the exchange rate will be equal to the difference between the percentage changes in the two price levels. Thus,

$$\partial r/r = \partial P/P - \partial P^*/P^* \qquad [2]$$

where

∂r	=	change in exchange rate
∂P	=	change in domestic price
∂P*	=	change in foreign price

r, P and P* remain as previously defined.

Most often governments set an exchange rate arbitrarily not tied to international market situation (Sarris, 1990). Reverting to equation [1], overvaluation means setting lower exchange rate relative to real or effective exchange rate. Therefore, if equation [1] is to hold true, at an assumed international or foreign currency, setting low exchange rate means low domestic price. Thus the price of tradeable goods when valued at the border price will be lower (Sarris 1990).

Moreover, the effect of overvaluation of the domestic currency is not only limited to the prices of domestic goods but also it does affect the prices of imported industrial inputs such as chemicals and petroleum fuels (ibid). These inputs are traded internationally and thus their domestic prices are tied to the international ones. In Tanzania the importation and domestic prices of the tradeable inputs is controlled by the government.

Fiscal policies

In analyzing the fiscal policies, the aspects to be considered are allocation of resources, inflation, interest rate and various taxes and tax rules which are envisaged to be more relevant in the Tanzanian context. The government often allocates a disproportionate low amount of resources to forest industries production. This curtails the possibility for expanding the processing capacity.

Another item falling under the fiscal policy is the rate of inflation. The rate of inflation in Tanzania has averaged between 20-30% during the period 1985 through 1991 (Bureau of Statistics 1991). One effect of inflation is that it pushes consumer prices up. It also tends to affect the borrowing capacity as bank interest rates become prohibitively high.

Interest rates have bearing on the development of forest industries especially where borrowing is necessary. For instance, in Tanzania, credits to production enterprises are extended by the Cooperative and Rural Development Bank (CRDB), which levies an interest rate of 28% per annum, embodying the inflation rate which averaged 20% in the middle of 1992 (EIU 1992). This is too high an interest rate to be recouped by a one year turnover giving rise to financial problems. That is, it is not easy to invest on an economic venture that has an annual turnover of at least 28%. In essence, therefore, the high interest rate in itself deters the would be loan seekers, in this case the forest industries. In some cases financial institutions are reluctant to extend loans to some small forest industries because such small industries are costly to serve and are risky clients they possess little collateral and their marginal socio-economic status renders uncertain the returns they gain from production.

Tanzania's public investment policy has been questionable for quite sometime (Gibbon, et. al. 1991). The main criticism is that public funds are spread over a lot of projects with less contribution to the welfare of the common or ordinary citizen, and economically less viable (Somogyi 1989; Gibbon, et. al. 1992). Further, the government committed itself to ambitious social obligations such as provision of free education and medical services (ibid). These commitments increased government spending substantially. Even when it faced huge budget deficits, the government was reluctant to change course (Somogyi 1989).

Finally the government has been protecting public enterprises through the provision of heavy subsidies and centrally planned production strategies. This situation has led to inefficiency and low turnover. This raises the question of choice of appropriate technology, the subject covered in detail by Solberg (1988).

FOREST INDUSTRY DEVELOPMENT AND POSSIBLE IMPACTS OF SAP ON FOREST INDUSTRIES

Forest industry development in Tanzania

Current structure

Under the structure which has been in use for several years, the forest industry in Tanzania has been owned largely by the government through the Tanzania Wood Industry Corporation (TWICO), a subsidiary of the National Development Corporation (NDC). The major role of TWICO is to plan, implement, coordinate, stimulate and control the development of the wood industry and trade in forest products (Kaoneka 1987; Kowero 1990).

Through TWICO the government is the main producer of hardboard, chipboard (particle board), veneer, plywood and most of the softwood sawntimber. Also, through NDC the government has almost monopolized the production of pulp and paper. Match production is the only large industry which is under exclusive private ownership. Despite TWICO's predominance, some district authorities still operate a number of hardwood sawmills and furniture making units. Predominant government ownership of the large wood processing mills in the country is partly a result of the nationalization policy which took place in the late 1960s to transform and put all major means of production under public ownership.

Private ownership of primary forest industries is largely limited to numerous small sawmills mainly using hardwood from the miombo woodlands and high forests. A limited number of private sawmills process softwood from plantations.

Pitsawing which is often organized on private basis by individuals exist in Tanzania particularly in areas where the tropical high forest is exploited. It produces about 40% of the country's sawntimber (TFAP 1989; Kowero 1990). Pitsawyers cut selected hardwood trees under license or illegally and convert them into lumber at the felling site. The rough sawn timber is then transported for sale elsewhere.

Present processing capacity

According to available forest industry statistics in Tanzania (Kaoneka 1987; TFAP 1989 and Kowero 1990), the installed wood processing capacity is as follows: the mechanical wood industry consists of about 130 sawmills, four wood-based panel mills (i.e. two plywood mills, one chipboard mill and one hardboard mill), one match factory and about 170 furniture and joinery enterprises. The hardboard mill also produces flush doors and clogs (wooden shoes) while several mills also impregnate fence posts and transmission poles. There are two main plants that impregnate telegraphic and power transmission poles. The pulp and paper industry comprises of one integrated pulp and paper mill, two non-integrated paper mills and seven major paper conversion plants.

There are also a number of wood processing artisans mainly located in urban and sub-urban centres where they engage in making furniture, carvings and other wooden handicraft products and also as producers of wooden components (doors, windows, wooden frames, etc.) for housing construction. Data for the precise quantity of wood consumed by this sector are not reliable.

Finally there are processing plants for the production of non-wood forest products. These include one tannin producing factory and one taxidermy plant for processing hides. There are also several private-owned small-scale enterprises which produce non-wood forest products such as medicine extracts, honey and beeswax, rubber, stuffing for cushions, pillows and mattresses, baskets, brooms, mats, straw hats, dyes, food supplements, oil, beverages and forage. Some of these operate as part of the handicraft industry.

On the basis of this installed capacity, the total wood processing capacity in 1992 was 900,000 m^3/year roundwood compared to 708,000 m^3/year in 1988 (Sharma, 1992). Indigenous hardwoods from natural forests account for about 300,000 m^3/year roundwood whereas plantations contribute about 600,000 m^3/year roundwood (Ahlbäck 1988; Sharma 1992).

It is estimated that only 37% of the wood supply from plantations is utilized by the existing processing capacity leaving wood surplus in industrial plantations which have a long-term annual allowable cut of about 1.6 million m^3 roundwood (Werner 1986; Ahlbäck 1986 and 1988). This surplus wood is simply standing as non-thinned or overmature wood in the plantations. One of the strategies to reduce this surplus could be the installation of more mobile sawmills (Kowero et al 1985, Solberg 1988, Kowero 1990). However, there is virtually no wood surplus in the natural forests because of the pressure for over-exploitation by local communities to meet their basic needs and also due to commercial utilization.

The performance of the existing wood processing mills is poor and hence is characterized by low capacity utilization, low recovery rates in wood processing mills and poor product quality (Kaoneka 1987). Also valuable logs especially of fine hardwoods are therefore partly wasted (Kaoneka 1987; Kowero 1990).

Several factors constrain performance. These include, aging machinery, foreign exchange shortage to purchase inputs and spares, managerial problems, frequent electric power failure, cash flow problems (due to very high operation costs, losses and overdrafts), poor infrastructure, poorly designed mills and obsolete machinery among others (Kaoneka 1987; Kowero 1990). For example, management problems and financial shortage have seriously affected the performance of the country's only integrated pulp and paper plant, the Southern Paper Mill (TFAP 1989).

There is also the problem of skewed market preference for a few popular indigenous species leading to overexploitation of these species in natural forests. Consequently, less than 30% of the capacity utilization of the mills that rely on these hardwoods is utilized due to the shortage of the raw material which is no longer easily available (O'Kting'ati & Kowero 1990). The shortage of fine hardwood species implies that the future demand will have to be largely met by plantation wood. However, this will require improvement in softwood timber durability and aggressive marketing to promote its consumption. The shift of the market to more use softwood timber would be a plausible achievement with positive impact on the protection of natural forests.

Possible effects of SAPs on forest industry development

Tanzania's economy has, for quite sometime, experienced turbulent trends which have affected the different production sectors. Productivity has been low in most important sectors including the forest sector. Tanzania signed an agreement with International Monetary Fund (IMF) and the World Bank under the structural adjustment programmes (SAPs). The agreement provided for a number of reforms including liberalization of trade, deregulation of foreign exchange controls, privatization, removal of subsidies, new marketing system, new finance system, etc. (EIU, 1992). Forestry industries being potential foreign exchange earners and embodied with high forward and backward linkages in the economy have been affected by these reforms. One change is the drive to privatize forest industries hitherto owned largely by the-government. Under this scheme some industries are to be sold to the private sector while others are to be jointly owned by the government and private shareholders.

Also following the liberalization of trade, the government initiated the "export to import" scheme under which a provision has been made for exporters to retain and use 50% of foreign exchange earnings for importation of industrial inputs.

Due to the lack of imported inputs, forest industries are operated at very low levels of capacity utilization. Even this low level of production is sustained by foreign aid which is likely to shrink in the future. Thus for a secure and better performance, increasing exports is the only viable option. This is pursued through raising production efficiency and diversification of export products.

Apart from foreign exchange scarcity, other factors that needed rectification to improve the situation include, insufficient production of popular timber, poor quality of the produce, lack of market for the more abundant lesser known timber species and uncompetitive free on board supply price (Moyo and Kowero 1986; Kaoneka 1987; Kowero, 1990).

Tanzania's traditional forest industry exports are tannin, wooden crafts, fine hardwood timber and very little softwood timber (Moyo & Kowero 1986). The current drive is to promote export of non-traditional forest products. It could be said that Tanzania's natural hardwood forests that serve export-oriented mills have limited raw materials to sustain large scale wood exports. However, these forests still have some stocks of lesser known general utility hardwoods which can be exploited on commercial basis.

In the current reforms, one long-term strategy is to diversify exports by promoting the marketing of general utility hardwoods for both the export market and domestic consumption. Similar efforts are underway to promote consumption of softwood timber both domestically and externally in order to make use of the probable wood surplus in plantations.

Under the bilateral and regional cooperation through the Preferential Trade Area (PTA) and the Southern Africa Development Coordination Conference (SADCC), trade with neighboring countries is promoted to get access to these markets. However, success depends on providing competitive prices, timely delivery and guaranteeing high quality product.

Renovation and expansion of existing wood processing mills is another change under current reforms. The aim being to improve quality of product and to increase output capacity. This goes together with infrastructure improvement especially the road network to facilitate transport of raw materials and industry outputs. Further improvements are by way of introducing extra mobile sawmills to process small logs and thinning plantation. Privatization in the forest sector is expected to play a positive role in this regard (Mitzlaff 1991).

Actual and anticipated changes

Partial analysis of the data so far collected indicates most of the forest industries to be utilizing about 50% or less of their installed capacity. Examples of these industries with their capacity utilization in brackets for the year 1993 are the Fibreboard Africa Limited (49%), Kibo Pulp and Paper Industry (54%), Tembo Chipboard Company (63% for the sawmill and 36% for the Chipboard plant)), Sao Hill Sawmill (above 90%), Kilimanjaro Timber Utilization sawmill (25%) and most other sawmills (about 50%). The major reason for this situation is the lack of capital(local and forex) to be able to renovate these factories and purchase spare parts and raw materials. Insufficient foreign exchange funding has forced the wood based industries managed by the Tanzania Wood Industry Corporation (TWICO), to operate at very low levels of capacity utilization (Moyo & Kowero 1986). Other major problems are the frequent power cuts, transport, inadequate trained manpower and low level of mechanization (Kaoneka & Ranfelt 1990). Consequently, most of these industries have not been operating smoothly over the past years. Generally the malfunction and inefficiency of these industries can be traced to the institutional set-up. Most of these industries are owned centrally and planned by the government through the Tanzania Wood Industry Corporation (TWICO). Under SAPs, some of these industries are in the process of being sold to private investors or going for joint ventures. The exercise is being conducted by the Presidential Sector Reform Commission. This arrangement is intended to improve efficiency. Some of these industries which the government has already advertized for outright purchase either the whole or a majority of the share capital are the Sao Hill Sawmill, Kilimanjaro Timber Utilization Company Limited, Kibo Paper Industry Limited and Sikh Sawmills(T) Limited.

METHODOLOGY

Research approach

In order to have a wider coverage, Tanzania was divided into five zones namely; Northern zone which includes Arusha and Kilimanjaro regions and Eastern zone which includes Dar es Salaam and Morogoro regions. Other zones have one region in each and they are Iringa, Mbeya and Tanga. For exports and imports, each region is treated as a zone. The major criteria used for zonation were the production (location of forest industries), consumption, forest stock (supply of raw material to the industries) and the distance between regions (transport).

Type or forest products

Forest products and types are many and decision was made on which products should be considered in the model. These were the products which are produced and consumed by or from these forest industries in significant quantities. Based on this, 15 products were chosen and they include logs (hardwood and softwood), pulpwood (hardwood and softwood), sawnwood (both hardwood and softwood), recycled paper, newsprint, packing papers, other writing and printing papers, hardboard, chipboard, plywood, charcoal and firewood. Out of these products, final products (from industries) were identified and they include all products mentioned above except logs and pulpwood.

Mode of field surveys

Each region under the study will be visited and regional data on forest stock, annual growth, timber supply from the forests and consumption of various final products in that region will be collected. To get these data, the region, districts, projects and the Division of Forestry offices will be visited. Structured and semi-structured questionnaire will be used to collect this information.

Various forest industries in each region will be visited, i.e., sawmills, paper industries, hardboard and chipboard factories and plywood mills. In these industries, the type of data to be collected include production statistics, costs, investment expenditure and product prices (local and export). Some of the transporting companies in each region will be visited to collect information on transportation costs (cost per km and per m^3 or ton), means of transport used and the distance between regions.

Information on consumption of various final products in each region will be collected through consumption survey and regional or/and district statistics.

Data analysis

Detailed analysis will be conducted after completion of data collection using a non-linear partial equilibrium model. The model has been in operation in Finland for several years and is presently being implemented in Norway.

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The impact of macroeconomic policies on the management of land resources in Tanzania

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SUMMARY

The environment has emerged as one of the major policy and research issues in the 1990s. Many countries, including Tanzania, have become increasingly aware of the consequences of environmental degradation. Hence a number of policies have been designed to offset the cost of degrading the environment. As one of the developing countries relying mainly on agriculture for its survival, Tanzania has sailed through the turbulence of the 1980s on a combination of resolute actions and generous external assistance amid near bankruptcy (Mans, 1994). After unsuccessful experimentation with own policies and amid pressure from external donors, Tanzania adopted the Economic Recovery Programme (ERP) in 1986. Though ERP was foreshadowed by structural adjustment programmes, as revealed by the contents of the 1984-85 budget, ERP(1) adopted in 1986 can only be likened to the Arusha Declaration of 1967 in terms of creating an environment which touched on every aspect of the society. Subsequent follow-up programmes have taken the design of ERP 1. How have these economic reforms affected land degradation and environment in the country is still relatively unknown.

Evidence elsewhere has indicated that this response has taken the form of extensification of agricultural activities in response to increased price incentives (see for example Cromwell and Winpenny 1993). Ironically this has led to more environmental degradation. The central question is then: given that Tanzania's economy is mainly agricultural-based, how can growth and environmental conservation be reconciled? This paper addresses the issue of macroeconomic policies on the management of land resources in an attempt to answer the above question.

The environmental problems common in rural areas in Tanzania include

(a) Deforestation: It is estimated that between 300,000 and 400,000 hectares of forest are cleared every year. The threat to forests is brought about by extending farmlands, demand for timber (both domestic use and exports), energy, etc.

(b) Soil erosion: It is mainly brought about by human activities (e.g. bad farming methods, overgrazing, etc.).

Both, economic and non-economic instruments are deployed for environmental protection.

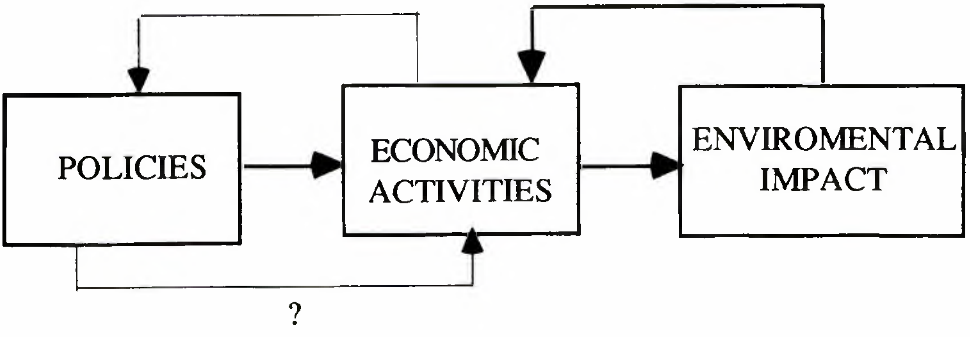

Figure 1. Economic Policies and Environment

There is no direct link between macroeconomic policies and land use (or the environment). The link is only indirect through the economic activities that result out of the policies and a possible feedback response of the environment to the activities. The matrix of actions and reactions is enormous. In fact, if one continues to juggle with different scenarios then a chain of simultaneous relationships occur as presented in figure 1.

The evidence is still based on partial data. However, responses like increased output and acreage due to increased producer prices is corroborated by other studies as well. Over all, macroeconomic policies appear to have both positive and negative effects. the positive effects include removing overvaluation of the domestic currency, increased agricultural output, positive GDP growth rates, etc. These are achievements that need to be amplified.

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Structural adjustment policies and the management of soil and forest resources in Tanzania

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Mayawalla, A.E.J. Strukctural adjustment policies and the management of soil and forest resources in Tanzania. Norwegian Journal of Agricultural Sciences. Supplement No. 21: 45-56. ISSN 0802-1600.

SUMMARY

Bearing in mind that Tanzania is basically an agricultural based economy, conducive policies need to be adopted for ensuring that its natural resources are well managed and rationally utilized. With the new policy of economic liberalization , the issue of natural resource management and utilization is very crucial and requires thorough analysis and proper planning. The impact of the macroeconomic policies should be critically analyzed as they have a direct bearing on the management of natural resources. The focus of this analysis is on discussing the impact of structural adjustment polices on forestry and soil resources. Since half of the country's potential area is covered by forests, it is quite clear that these resources will be largely affected as the livelihood of most Tanzanians depend on agriculture. The agricultural sector employs about 90 per cent of the total labour force and accounts for 50 per cent of the GDP and 75 per cent of the foreign exchange earnings. Forestry sector contributes about 4.3 per cent of the GDP. Taking into account the role of forestry sector in the economy, one has to look into the impacts of the structural adjustment policies now in place.

In a liberalized economy, restrictions on various economic undertakings are eliminated, the tax base is broadened and the prices are decontrolled. These measures provide incentives to the producers. This being the case, forests are in danger of being depleted for various purposes. More forested land is being cleared for expanding agriculture, including that for shifting cultivation and for livestock grazing. Over exploitation of forest resources may also occur due to increased demand for charcoal burning, firewood, building materials, and timber. Fish smoking and tobacco curing may also threaten the forest resources.

The current estimates on deforestation stand at 130,000 hectares per year, while tree regeneration and replacement is 25,000 hectares per year. Commercial investors are interested in maximizing profit by harvesting wood for domestic and export purposes. Lack of alternatives particularly for the low income earners contribute much to depletion of forests since their livelihood depend on subsistence farming. All these activities cause land degradation and other environmental

hazards through a reduced forest cover causing increased run off and soil erosion.

Structural adjustment policies may also have some positive impacts on forestry development. These policies could promote the role of forestry research compared to the past policies particularly on promotion of quality products and discovery of new products. Private sector involvement in economic development could promote quality products and thus more competition in forestry products.

The economic reforms being currently undertaken should aim at preserving the long run productivity of natural resources for sustainable development and at minimizing deterioration in the quality of the environment. Some of the outstanding measures to reverse the present trend in deforestation should include:

1. Undertaking large scale afforestation programmes.
2. Efficient utilization of wood by using improved charcoal stoves and alternative sources of energy like coal, biogas, solar and wind.
3. Creating people's awareness on scientific forest management.
4. Economic development activities should be concerned with maintaining natural systems.
5. Structural change to ensure the use of natural resources consistent with growing incomes and expanding material wealth.
6. Enforcement of laws and regulations to control the abuse of natural resources.
7. Integration of environmental issues in planning from the rural household level right up to the national level.
8. Review of land policy and land tenure system to ensure right ownership of resources.
9. Rational pricing of forest products.

Predicting soil degradation in Tanzania- a system analysis approach

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Aune, J.B.Predicting soil degradation in Tanzania- a system analysis approach. Norwegian Journal of Agricultural Sciences. Supplement No. 21: 47-60. ISSN 0801-1600.

A model for predicting long-term productivity for crops grown in Tanzania is developed. The model predicts changes in productivity over 30 years period for maize, sorghum, wheat, rice, beans, groundnuts, cotton, coffee, tea and sisal. The time step of the model is one year. The model describes changes in soil organic carbon, total nitrogen, pH and soil erosion. It allows the user a free choice as what crops to grow, how much fertiliser, manure and lime to apply and what kind of plant protection measures to use for the next 30 years. When running the model using input data from Tanzania it was found that productivity of Tanzanian soils will decline unless measures are taken to reverse the situation. It appears the main factor causing decline in productivity is reduction in nutrient availability through soil mining and soil erosion. Build up of soil acidity is also a potential future threat to productivity of Tanzanian soil, especially if strongly acidifying fertilisers are used.

Keywords: crop choice, model, pest management, soil management, yield prediction, soil erosion.

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Predicting future productivity is an extremely important, though difficult task. Models can be a usefull tool for resource management at the farm level as well as in development planning at national level. They can be used to assess how resources should be managed in order to maximise production with minimum environmental negative effects (analysis of sustainability).

If a model is to be used in economic analysis for development planning, not only all agricultural crops but all main factors limiting productivity should also be included in the model. The reason all crops need to be included is that every year the farmer has to choose which crops to plant. Existing models like CENTURY (Parton et al. 1987), DSSAT (DSSAT 1989), and QUEFTS (Janssen et al. 1990) are only able to cater for a very few of the crops grown, and account for only some of the soil factors limiting productivity. None of the existing models is for example able to cater for the acidifying effect of fertilisers. Existing models, therefore, tend to overestimate yield on acid tropical soils.

A new model is, therefore, being developed at the Agricultural University of Norway for predicting future yield and soil properties as effected by soil and crop management for all the main crops grown in Zambia and Tanzania The crops are maize, sorghum, rice, wheat, beans, cotton, cassava, tobacco, coffee, tea and sisal. Sequences of crop and soil management systems can be set up in the model allowing for analyses of different scenarios. All the main soil related factors limiting productivity in Tanzania as defined by Mnkeni 1993 are included in the model. The model can be used for the following purposes:

- predict yield response to NPK fertilisers (organic and inorganic) and lime
- assess the effect of crop and soil management on long term productivity
- predict changes in soil properties as affected by soil and crop management
- quantify the effect of erosion on long term productivity and the relationship between agricultural practices and soil erosion
- assess the effect of plant protection measures on yields

MODEL OUTLINE

The general outline of the model can be described as follows.:

$$Y_t = \text{Potential yield} * N_t * P_t * pH * SOC * M_t \quad \text{Eq. 1}$$

where Y_t is yield in kg/ha in year t, potential yield is the climatically determined yield level in kg/ha (the highest possible yield determined under ideal conditions), N_t, P_t, pH_t, SOC_t, and M_t are time dependent indices (1 year time step) ranging from 0 to 1 respectively for nitrogen, phosphorous, pH (acidity), soil organic carbon and management (weeding, fungicide application etc.). If the index is 1 for a specific factor, this implies that this factor is not constraining productivity. These indices are crop specific (Aune & Lal 1995).

These indices were obtained by analysing fertilizer, liming and pesticide experiments. The relative yield in each of the experiments was obtained by dividing the yield in each treatment with yield in the highest yielding treatment. A new data set combining different experiments was then created where four data points were selected from each experiment in order to overcome the problem that the number of treatments varies between the experiments. In this way, each experiment has the same influence on the shape of the curve. Regression analyses were then undertaken across locations between the soil property and relative yield.

If locally established functions are available for the relationship between growth factors and yield, it is preferably to use these functions. The model is programmed in the spreadsheet Excel 4.0, making it easy to replace functions.

Nitrogen cycle

In order to describe the changes in the nitrogen factor, a mathematical description of the nitrogen cycle was developed. As figure 1 shows, the nitrogen cycle is a highly complex cycle with flows running in many directions. The nitrogen cycle is also effecting other processes as soil erosion and acidity build up.

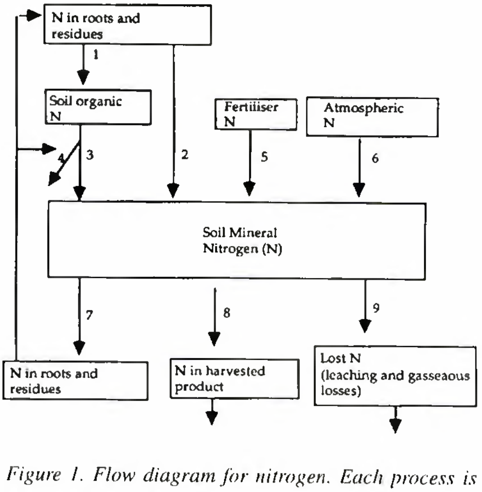

Figure 1. Flow diagram for nitrogen. Each process is assigned a number

The main pool of nitrogen in the soil is found in the soil organic matter. This nitrogen is however tightly bound and is not directly available to plants. When the soil organic matter decomposes, mineral nitrogen is released (NO_3^- or NH_4^+). This is the form in which nitrogen is taken up by plants. Plant residues and organic manures also contain substantial amount of nitrogen. As for soil organic nitrogen, this nitrogen is not directly available to plants, but is being released as mineral nitrogen when residue decomposes. Fertilisers supply nitrogen in a form which is directly available for plant uptake. Nitrogen in the mineral form is taken up by plants and a part of this nitrogen is recycled if crop residues are retained in the field. Nitrogen is removed from the system through export with harvest products, gaseous losses, by soil erosion and leaching. A more detailed and mathematical description of the nitrogen cycle follows.

Process 1 and 2. Decomposition of roots and residues

The release of nitrogen in the model is based on the findings from both tropical and temperate regions that about 30 per cent of the total nitrogen in straw and roots enters into soil organic matter (Ladd & Amato 1985, Uhlen 1991). To correspond with a final incorporation percentage of 30, the model transfers 25 percent of the total nitrogen in residues directly into soil organic nitrogen (SON). This fraction represents the recalcitrant (stable) components of the nitrogen in residues. When the stover nitrogen is recycled to the soil next year, it will add to the quantity of N transferred directly into SON the year before and generates the final result that about 30% of nitrogen in straw is incorporated into the soil organic matter.

The remaining 75 per cent (ß=0.75), of the nitrogen will be mineralised over a period of 4 years as observed for residues with a carbon/nitrogen ratio above 25 in experiments in Nigeria (Jenkinson & Ayanaba 1977). Accordingly, the following relationship was established:

$$N_{rm(t)}=0.33 \sum_{i=2}^{4} ßN_{r(t-1)} \qquad \text{Eq. 2}$$

where $N_{rm(t)}$ is nitrogen mineralised from residues in year t, $N_{r(t-1)}$ the amount of nitrogen in residues in year t-i, ß=0.75 is the proportion of residue nitrogen available for mineralization. This formula shows that slow decomposing N sources will be mineralised over a period of three years with a lag period of one year.

Process 3. Decay of soil organic nitrogen (soil humus)

The decay of soil organic nitrogen (SON) from humus can be described according to an exponential decay (Nye and Greenland 1960).

$$N_{s(t)}=N_{s(t-1)}\, e^{-rt} \qquad \text{Eq. 3}$$

where $N_{s(t)}$ is the total soil organic nitrogen in year t in the upper 20 cm of the soil, $N_{s(t-1)}$ is soil organic nitrogen in year t-1, r is decomposition constant set to 0.04 (Nye and Greenland 1960 and Young 1990) and t is year.

Soil erosion and addition of residues will effect the future capacity of the soil to mineralise N from the SON pool. In order to account for this, the following relationship was established:

$$N_{s(t)}=N_{s(t-1)}\, e^{-rt} + N_{r(t-1)}\,(1-ß) - N_{e(t-1)} \qquad \text{Eq. 4}$$

where Nr is the amount of nitrogen added by residues and Ne is the annual loss of nitrogen through soil erosion.

The amount of nitrogen mineralised $N_{SON(t)}$ annually is:

$$N_{SON(t)}=N_{s(t-1)}\,(1-e^{-r}) \qquad \text{Eq. 5}$$

Process 4. Soil erosion

The loss of nitrogen is calculated according to the FAO version of the Universal Soil Loss Equation (FAO 1979) (Eq 6).

$$N_{e(t)}=R*K*S*C_{(t)}*N_{c(t)}*E*1000 \qquad \text{Eq. 6}$$

where $N_{e(t)}$ is kg N/ha lost in soil erosion, R-climatic factor, K-soil erodability, S-slope factor, $C_{(t)}$-cover factor, $N_{c(t)}$-nitrogen concentration percent in the soil, E-nitrogen enrichment factor. However the R, K and S factors in the USLE equation are calibrated in order to predict soil loss in correspondence with the observed levels of soil loss.

The annual loss of nitrogen through soil erosion is made time dependent because the vegetation cover C_t and nitrogen concentration $N_{c(t)}$ will change as a function of decline in SON due to decomposition and past soil erosion.

The nitrogen enrichment ratio has to be given to account for the fact that eroded materials are more rich in nutrients than the soil it originates from. This ratio can according to Foster (1988) be set to 2. The cover factor is dependent on the choice of crop (Roose 1977) and for cereals it is also dependent on the yield obtained. For cereals the following relationship was developed with data from Roose (1977) for $C_{(t)}$ factor:

$$C_{(t)}=1 - 0.0001*Y_{g(t)}, \qquad \text{Eq. 7}$$

where $Y_{g(t)}$ is grain yield/ha.
$N_{c(t)}$-nitrogen concentration in soil (time depended) and is calculated as follows:

$$N_{c(t)}=N_t/BD*100000*D_t \qquad \text{Eq.8}$$

where BD is bulk density of top soil and D_t is remaining depth of top soil in m. D_t is calculated as follows:

$$D_t=0.20-\frac{R*K*S*C_t*10000}{BD*10000*0.01} \qquad \text{Eq. 9}$$

Process 5 Fertiliser application

Nitrogen in fertiliser (N_f) is assumed to be directly available for plant growth. The efficiency of fertiliser is therefore set at 1. This does not imply that all N fertiliser is taken up by plants, but it gives the efficiency of fertilizer N compared to other sources of nitrogen.

Process 6. Atmospheric deposition of nitrogen

Nitrogen from wet deposition can be calculated according to the following formula (Smaling and Fresco 1993):

$$N_A=0.14*\sqrt{\text{mm annual rainfall}} \qquad \text{Eq. 10}$$

where N_A is kg N/ha per year.

Process 7. Transfer of nitrogen into residues and roots

The amount of nitrogen transferred into stover Yst(t) is calculated by using the following formula.

$$N_{st(t)}=\text{Potential yield } Nt*pH_t*SOC_t*P_t*M_t*SG*N_{cs} \qquad \text{Eq. 11}$$

where SG is the stover/grain ratio and Ncs is nitrogen concentration in stover.

For annual crops, the root system is assumed to be approximately 30% of the total biomass. The nitrogen content of the root system $Y_{ro(t)}$ for annual crops is therefore calculated as follows:

$$N_{ro(t)}=((Y_{s(t)} + Y_{g(t)})*(30/70))*N_{cr} \qquad \text{Eq. 12}$$

where $Y_{s(t)}$, $Y_{g(t)}$ and N_{cr} is stover yield, grain yield and nitrogen concentration in roots, respectively.

Process 8. Yield formation

The grain yield was calculated according to the following formula:

$$Y_{g(t)}= \text{Potential yield}*N_t*pH_t*SOC_t*M_t \qquad \text{Eq. 13}$$

where $Y_{g(t)}$ is yield in kg/ha.

Nitrogen available for plant growth

Nitrogen available for plant growth is calculated as follows

$$N_{min(t)}=N_{F(t)}+\frac{N_{rm(t)}+N_{SON(t)}+N_{A(t)}}{2} \qquad \text{Eq. 14}$$

where N_{min} is the amount of nitrogen available in the mineral form, N_F is the amount of fertiliser N used, N_{rm} is the amount of N mineralised from residues and N_A is the addition through atmospheric deposition. Only half the amount of nitrogen mineralised from plant residues, soil organic nitrogen and atmospheric deposition is available for plant growth due to lack of synchrony between the nitrogen released from these forms and plant demand.

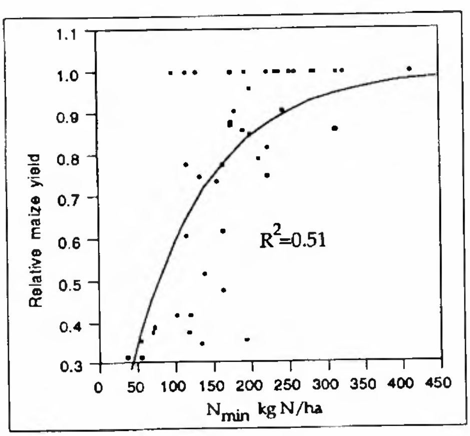

Figure 2. Relationship between available nitrogen and relative maize yields

The nitrogen factor

The relationship between N_{min} and relative yield for various crops is established by analysing fertiliser experiments from Tanzania (Mowo et al. 1994, FAO 1992) (Fig. 2). The capacity of the soil to mineralize nitrogen was taken into account by adjusting for mineralisation from the soil organic nitrogen according to equation 5 and 14. The functional relationship between N_{min} and relative maize yield is given below:

$$N_t=1-1.067*e^{(-0.0095*N_{min})} \qquad \text{Eq. 15}$$

Similar functions have been developed for the other crops.

Acidification

Nitrogen fertilisation and mineralisation of nitrogen from residues will influence the pH of the soil through its transformation in soil (figure 3).

The effect of nitrogen supply on acidity will be depend on the form nitrogen is added to the system and on the degree of nitrogen cycling. Figure 3 illustrates that if nitrogen is supplied as ammonium sulphate, the net effect on acidity will be zero under a situation of complete nitrogen recycling. This is never the case in agricultural systems. The acidifying effect of ammonium based fertilisers will be maximised if all the added nitrogen is leached. Removal of crop residues will also have an acidifying effect, because the potential alkaline effect of decomposing crop residues will then not be realised.

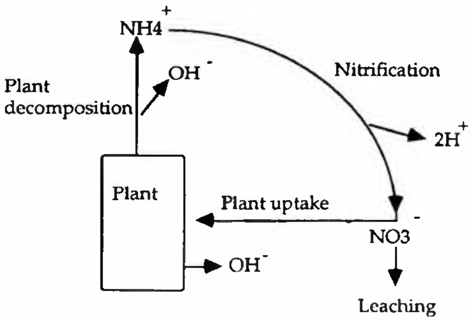

Figure 3. Simplified figure of the effect on nitrogen cycling on acidity (adapted from Helyar 1976)

A model for predicting pH changes as a result of fertiliser and cultivation history was established by analysing 6 long-term (5 years) N-fertiliser experiments from Southern Highlands of Tanzania (Uyole Agricultural Centre 1991) and 1 long term experiment from Mwanza, Tanzania (Le Mare 1972). The following model was developed:

$$pH_t = pH_{(t-1)} - 0.00091 N_{t-1} \Omega - 0.018 \quad \text{Eq 16}$$

where pH_t is pH in year t, pH_{t-1} is pH year N_{t-1}, N_{t-1} is kg N/ha in fertilisers supplied last year, Ω is acidifying effect of fertilisers and 0.018 is the annual change in pH as a result of cultivation. This formula implies that pH is reduced by 0.00084 unit per kg of nitrogen added as ammonium sulphate and is reduced by 0.018 units per year of cultivation.

The form in which the nitrogen is supplied will also affect the acidity build up. If nitrogen is supplied as sulphate of ammonium, the acidifying effect of this can be set at 1, having maximum acidifying effect. Adapted from Helyar 1976, the different sources of N were assigned an acidifying factor (Table 1).

Lime can be added to reduce acidity. The effect of liming on pH was established by analysing 7 liming experiments from the Northern Province of Zambia (SPRP 1987, SPRP 1990, Tveitnes and Svads 1989, Singh 1989, Øygard 1987). The average effect of lime was calculated in each of these experiments and the average regression coefficient was established. The effect of liming on pH can therefore be calculated as follows:

Table 1. Relative acidifying effects of fertilisers per kg of mineral N supplied (Ω value). 1- maximum acidifying effect.

Ammonium sulphate	1
CAN-calcium ammonium nitrate	0.25
Urea	0.33
Calcium nitrate	-0.25
NPK fertilisers	0.5
Ammonium nitrate	0.5
Green manures	0.5

$$pH_t = pH_{t-1} + 0.27 \text{ tonnes } CaCO_3/\text{ha} \quad \text{Eq. 17}$$

where pH_t is pH after liming and pH_{t-1} is pH before liming. This formula implies that pH will be increased by 0.27 units per ton of $CaCO_3$.

By comparing Eq. 16 and 17 it appears that for every kg of N applied as sulphate of ammonium, 1.74 kg of CaO (3.11 kg $CaCO_3$) should be added. For temperate climates it has been found that for each kg of N added as ammonium sulphate, 1.0 kg of CaO should be added (Finck 1982). This higher lime requirement for these soils per 1 kg N might be explained by a higher percentage of N being leached from tropical soils and lower degree of nitrogen cycling through residues.

Pests and diseases

Yields are often reduced due to attack of pests and diseases. It was therefore required to include this effect in the model.

Cotton is especially vulnerable to pink bullworm (Pectinophora gossypiella) (Kabissa 1990). Kabissa (ibid) reports that six routine sprayings of deltamethrin increased the number of pickable bolls by 50% . From Kenya a 30% reduction in yield due to the pink bullworm is reported (Walker 1987) and the world-wide estimate for yield reduction of cotton due to pests is 38%. From Zambia a 50% yield reduction is reported due to the disease (Javaid 1990). It can therefore be assumed that cotton yield can be reduced by approximately 40% when pests are not controlled. The following relationship between number of sprayings and yield reductions was established by assuming a linear relationship:

Relative cotton yield=0.6+0.067* number of sprayings

The maximum number of sprayings is 6.

Important coffee diseases in Tanzania are Coffee Berry Disease (Colletotrichum coffeanum) and Coffee Leaf Rust (Hemileia vastatrix). Results from two fungicide experiments (Nsemwa and Mwambene 1992) showed that yield in control plots were only 20% of the yield obtained in treatments with 5 sprayings. The following formula expresses the relationship between number of sprayings and relative yields:

Y=0.23+0.15*number of spraying

The maximum number of sprayings is 6.

PREDICTING LONG TERM PRODUCTIVITY IN TANZANIA

All agriculture which involves selling of products must be considered as a nutrient exporting activity. Nutrients will have to be replenished if production is to be sustained. These nutrients constitute one of the fundaments on which all agriculture depends. Stoorvogel and Smaling (1990) have calculated that annual net removal of nitrogen from agricultural land in Tanzania is 27 kg N/ha and annual removal of P is 4 kg/ha. These figures indicate that the resource base for Tanzanian agriculture is gradually eroding and yields will decline unless measures are taken to reverse the situation.

However, to get insight into how productivity of agricultural land in Tanzania will develop over time it is not sufficient to calculate a nutrient balance only. There is also a need to establish a relationship between changes in supply of nutrients and productivity and the interactions between nutrients supply and other factors affecting productivity such as pests and diseases. This can only be done within a modelling framework. Functional relationships between nitrogen supply, SOC level, pH level and pests were therefore developed.

Tanzania has very contrasting ecological conditions. The model will therefore have to be run separately for each region. A characterisation of the soil in the different regions of Tanzania was obtained from various soil surveys. The model was run using these data as input. As Table 2 shows, the soils of the Kilimanjaro region has the highest fertility, while the soils of Mwanza region are the poorest.

A survey of measurements of soil erosion in Tanzania was undertaken (table 3). The measurements are obtained from runoff plots and from catchments. Measurements of soil erosion from cultivated area without soil conservation measures varied from 6 to 52 tonnes/ha. Forest land has a neglectible soil erosion. The USLE equation was calibrated by adjusting the rainfall factor to fit observed values.

Table 2 . Soil properties in some agroecological zones of Tanzania

Region	Soil type	N %	pH	P mg/kg
Southern highlands	Ferralsol	0.16	5.75	6
Kilimanjaro	Haplic phaeozem	0.24	6.3	67
Mwanza region	Various soil types	0.068	6.31	10.1

Table 3. Quantities of soil erosion from various sites in Tanzania

Location	Soil type	Treatment,	Erosion tonnes/ha	Reference
Mlingano	Rhodic ferralsol	Bare soil	37	Ngatunga & Lal 1984
		Plowed	14	
		Mulched	0.12	
Tengeru	-	Coffee, clean weeded,	22	Kaihura 1991
		Maize , stover removed	12	
		Maize, trash bunds	1	
		Banana	0.5	
Mpwapa	-	Bare soil	116	Temple 1971
		Ridge cultivation	52	
		Millet/sorghum	62	
		Grass	0	
Ikoa, Msalatu	-	Catchment		Christianson 1981
Imazi,		Cattle grazing and cultivat.	6	
Matam-bulu		Bare land	120	
Ukiguru mountain	-	Catchment		Rapp et al. 1971
		Forest and cultivated area	4	
		Cultivated area	40	

Model validation

Models are best tested against long-term experiments. Such data are very much lacking from the African continent. An extensive testing of the model has therefore not been possible. A preliminary testing of the model was done using results from a 17 year old fertiliser experiment with 3 levels of fertilizer nitrogen from Kasama in Zambia. This region has very much the same agroclimatic conditions as the Southern Highlands of Tanzania. The observed data in the Zambian experiment were smoothened to remove the effect of weather variation on yield. When testing the model, a liming function developed from Northern Zambia was used. The R^2 between observed and predicted values was 0.75, telling that the model was able to account for 75% of the yield variations in the Zambian long-term experiment. The model gave quite accurately yield prediction at higher and at lower yield levels, but overestimated the yields at intermediate levels. A probable reason for the discrepancy between observed and model predicted values at intermediate yield levels might be related to a higher sensitivity to acidity of the maize variety used in the experiment than of the maize varieties in the experiments that were used to construct the model.

Effect of soil erosion on maize productivity in the Southern Highlands of Tanzania

The Southern Highlands of Tanzania is the main maize producing area of Tanzania. As table 1 shows, the soils are considered to have a moderate fertility. Four different scenarios for the Southern Highlands of Tanzania was established. The effect of a soil erosion of 15 tonnes/ha is compared to no soil erosion under two different levels of fertilizer use (Figure 4). The annual decline in productivity when no fertiliser was used was 6.4 and 4.7 per cent respectively with 15 tonnes soil erosion/ha and without soil erosion. Soil erosion had a less pronounced effect on productivity where 100 kg N/ha was applied annually. Under this condition, the annual decline in productivity was with 15 t soil erosion/ha and without soil erosion was respectively 3.2 and 2.5 per cent. In all cases farmers will therefore experience a decline in productivity. This decline is related to a reduction in the soil organic nitrogen content, a decrease in the soil organic carbon content (detoriation of soil physical properties) and a build up of soil acidity.

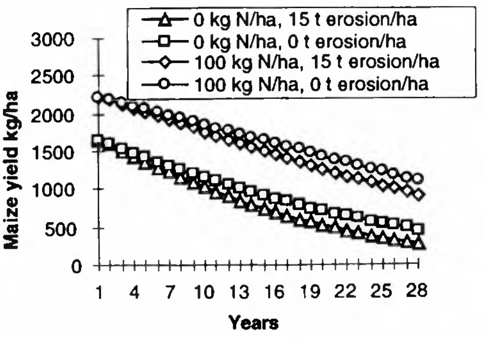

Figure 4. Effect of soil erosion and nitrogen fertilisers on long-term maize productivity in the Southern Highlands of Tanzania

Effect of soil acidity as effected by use of fertiliser on maize productivity in the Southern Highlands of Tanzania

Changes in pH as a result of fertiliser use can also cause a decline in productivity. This decline will depend on the initial pH and the amount and type of fertiliser used (equation 16). The effect of choice of type of fertilizer was examined in a moderately acid soil in the Southern Highlands of Tanzania. If sulphate of ammonium (SA) is used as a nitrogen source, yield will decline to zero within 20 years, while if calcium ammonium (CAN) is used, productivity is approximately 1100 kg/ha after 30 years (Fig. 5).

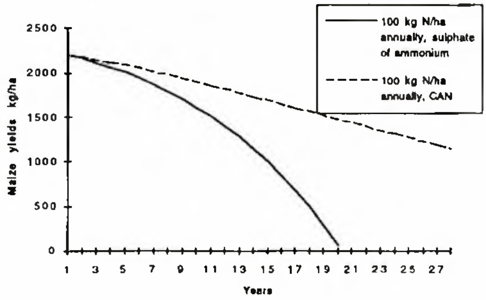

Figure 5. Effect of annual application (100 kg N/ha) of calcium ammonium nitrate and sulphate of ammonium on long-term mazee productivity

Figure 6 depicts that SA will have a very dramatic effect on pH. Within a period of 18 years, pH will drop from 5.75 to 4. Below a pH of 4, no maize can be grown. If CAN is used, there is also a decline in pH explaining the declining yield in figure 4, but this decline is much less dramatic than if SA is used. These data clearly illustrate that liming is a prerequisite if productivity is to be sustained.

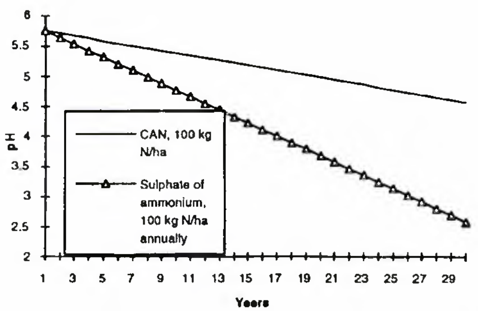

Figure 6. Effect of annual application (100 kg N/ha) of calcium ammonium nitrate and sulphate of ammonium on pH

Cotton production in the Mwanza region of Tanzania

In the Mwanza region, cultivation of cotton is an important activity. Yields are low because soils are low in SON and because attack of cotton bullworm. Figure 7 illustrates that yield will decline further if no counter measures are taken. Fertiliser application and the use of pesticides can increase production from 600 kg/ha to 1100 kg/ha. Figure 7 shows a scenario where cotton is grown without any fertilisers and plant protection measures for the first 15 years. From the 16th year, fertiliser N is added at a quantity of 60 kg N/ha. From the 22nd year annual spraying against pink bullworm is practised together with application of fertilizer. It appears that both fertilizers and pesticides are able to increase yields.

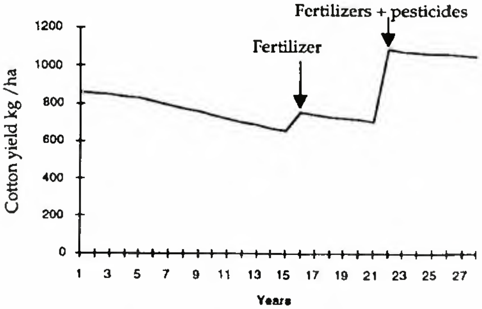

Figure 7. Cultivation of cotton for the first 15 years without adding fertilisers, from year 16 adding 60 kg/N annually and from year 22 spraying against pink bullworm

Coffee production in the Kilimanjaro region

Coffee is an important crop in the Kilimanjaro region of Tanzania. Figure 8 illustrates a scenario if coffee is replaced with a maize monocropping system. It appears that the coffee system is a much more sustainable system than the maize system. The model predicts that the maize yields will drop from about 3000 kg/ha to about 2000 kg/ha within a period of 15 years (Figure 8). Soil erosion is a major factor explaining this decline because it is only about 7,5 t/ha in the coffee system whereas it is increased to approximately 25 t/ha in the maize system (Figure 9). This quantity of soil erosion is less than the quantity measured in the Uluguru mountains of Morogoro which has agroecological conditions similar to the Kilimanjaro region.

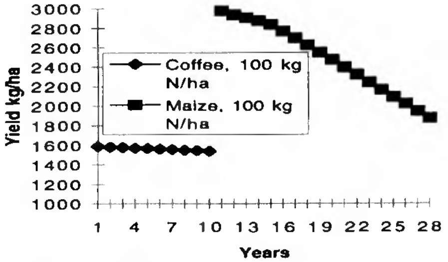

Figure 8. Kilimanjaro region. Coffee for the first 10 years, thereafter maize

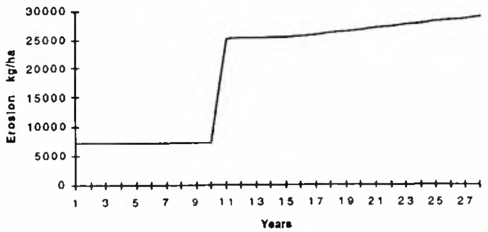

Figure 9. Effect on soil erosion of cultivating a sequence of coffee for the first 10 years and thereafter maize

CONCLUSION

A system analysis approach to the analyses of sustainability can provide insight into how the productivity of the cultivated area will develop. Even though that there is considerable insecurity related to the data presented concerning the magnitude of the loss of productivity, the figures presented illustrate that productivity will decline at a significant rate unless measures are taken to reverse the situation. There is a special need for improving the supply of nitrogen. This can either be done by improving the supply of fertilisers and by introducing agroforestry or green manuring practises. At the same time, it is necessary to introduce measures which can control soil erosion. The build up of soil acidity in Tanzanian soils need also to be checked. It can therefore be concluded that there is a potential for increasing production. If farmers are given the right incentives, productivity will increase.

There seems to be no general contradiction between the need to raise agricultural production and preserving the environment. Increased yields normally imply a better soil cover which will reduce soil erosion. However, the most dominant factor in controlling soil erosion is the choice of crops. In the steep slopes in some of the most fertile regions of Tanzania it is important to include a perennial component in the cropping system. An economic policy that stimulates the use of perennial crops will therefore be the single most import decision to maintain the productivity of the agricultural land in Tanzania. This perennial component will reduce soil erosion and thereby assist in preserving the productivity of the most fertile lands of Tanzania.

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Establishment of Criteria for Distinguishing levels of Past Erosion in Tanzania

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Soil morphological characteristics are used to identify topsoil depth limit for delineation and definition of the extent of cumulative past erosion. A criterion linking topsoil depth and extent of past erosion is proposed. The following topsoil depth ranges: < 15 cm, 16-20 cm, 21-25 cm, and > 25 cm are considered to reflect severely eroded, moderately eroded, slightly eroded, and least eroded phases of accelerated past erosion, respectively. The possible influence of agro-climatic and soil characteristic differences among studied sites to amplify or mask erosion effects on current crop productivity are discussed.

Keywords: erosion classes, erosion classification, field methodology, tropical soils, profile characteristics

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During 1980's and 1990's the concern about the sustainability of agricultural systems in Africa has increased tremendously. The main cause for the concern is associated with the frequent food deficits and the characteristic slow economic growth rate. Where data is available, better land resource management systems have been employed with success. A few such examples include the rehabilitation of the formerly erosion devastated lands of Kondoa in Tanzania (Nshubemuki & Mugasha 1985) and the management of low fertility soil resources in South America (Sanchez 1982; Serrao et al. 1979). A number of factors could be responsible for the non sustainability of the agricultural production systems of the inter tropical region. However, Pimentel at al. (1990) point out that soil erosion is a major threat to the available agricultural land - hence, a major threat to a sustainable agriculture. Erosion -induced productivity decline in Africa is considered as a possible principle factor for the perpetual food deficit (Lal 1995). Laflen et al. (1990) attribute part of the starvation seen in some areas of Africa to soil erosion. Areas affected by water erosion are numerous in Africa. Water erosion affects much of Africa in spite of the continent´s tremendous deserts. FAO (1965) and Lal (1995) provide an elaborated account on soil erosion in Africa.

Controlling soil erosion is expensive, time consuming and requires scientific approach for it to be sustainable. A lot of information is needed so as to employ modern technology to predict soil erosion rates and their impact to the economy under specified agricultural management systems. The diverse nature of soils, climate, land use systems and the associated differences in their management coupled with limitated soil erosion research facility affect the rate of data generation for use both at country and regional level. In deed, quantitative data on the effects of soil erosion on crop yields under different systems of management are available only for a few sites in Africa (Lal 1995).

A number of approaches have been used to study the impact of soil erosion on productivity. These have been reviewed by Lal (1987). They could be grouped into the following categories: direct field measurements of yields on agronomic experiments accompanied with or without soil loss data, new erosion plots under natural or simulated rainfall, greenhouse and laboratory studies, assessment of soil properties by field surveys, geomorphological approach to determine soil loss tolerance, and crop productivity models.

Taking into account the wide distribution of accelerated erosion in the tropics, notably in Africa (Lal 1995) there is need to assess and map the cumulative effects of past erosion on current crop production. Such data will enable individual governments to make priorities on land conservation based on economic criteria. A simple but reliable methodology is required to fulfil this task. The objective of this paper is to work out a simple technique to determine different degrees of past erosion which could be tested in the field and eventually be used for producing national or regional maps.

MATERIALS AND METHODS

These experiments were conducted in different agroecoregions of Tanzania, namely Kilimanjaro, Tanga, and Morogoro. These represent humid, sub humid and sub humid- semi arid transition zone. Similar eco-regions constitute typical maize growing areas in Tanzania. The detailed characterization of these agroecological zones was carried out by De Pauw (1984). Characteristics of the three eco-regions are shown in Table 1. The eco-zones differ markedly in rainfall, geology of the parent material and dominant soil type or soil characteristics. These differences are likely to influence crop productivity and hence become one of the sources of variation of yield data among the eco-regions studied.

The sites in the Kilimanjaro region, Kirima-Boro and Xeno Helena have a mean annual rainfall of 1500 mm, spread into two seasons: November-December and March-June. Mlingano 1 and 2 sites in the Tanga region have a mean annual rainfall of 1140 mm, mainly spread between September-December and mid March-June. The Misufini and Mindu sites in the Morogoro region have a mean annual pre-cipitation of 861 mm which falls between November - December and midi March -early May. The Mindu site is drier than the Misufini site. The Mindu site received in the 1992/193 seasons 100 mm less rainfall than the Misufini site and the rainfall season was 2 weeks shorter.

Predominant soils of each eco-region were taken into account in selecting sites for the study. Accordingly therefore, two sites were selected in both Kilimanjaro and Tanga while a total of four were chosen in Morogoro.

The study was done on agricultural lands with known recent history of management practices. The chosen sites have only suffered from water erosion. However, gullies and landslides are rare on the sites.

An area of about two hectares was earmarked for the study at each site. The idea was to select a large piece of land to include each possible details of past erosion.

Each site was topographically surveyed to prepare a topographical map at a scale of 1:100 with a contour interval of 10 cm to display the spatial variability of the land geomorphology. Surveyed areas were divided into 5 metre grid points at which mini-pits (30 by 60 cm wide) were dug to the depth of 50 centimetres. Soil morphological characteristics were systematically observed from the ground surface to 50 cm depth in order to determine the boundary between the topsoil and the underlying subsoil. The morphological characteristics used were: soil consistence both under field moisture and wet soil conditions, soil colour as determined by Munsell colour chart, and soil texture. Topsoil depth classes were worked out in association with degree of cumulative past erosion.

At Tanga, some areas had a shallow stone line notably at site 2. At Morogoro, eco-region, a layer of resistant rock appeared at shallow depth at some sites. In both cases the exact depth from the ground surface to the layer concerned was determined by augering at 5-metre grid points. At each site, a pit of 2 m by 1 m by 2 m (or shallower where there was an impeding rocks) was dug for profile description and soil sampling. Soil profile description was done following the guidelines worked out by FAO (1977).

Soil samples collected from individual horizons were air dried and sieved through a 2 mm sieve. The fine earth (< 2 mm) was used for various laboratory analyses. Particle size distribution was determined by sieving and by the hydrometer method (Gee & Bounder 1986). Chemical properties determined included cation exchange capacity (CEC), pH (H_2O) and pH (KCl), organic carbon, total nitrogen and available phosphorus. Cation exchange capacity was determined by neutral ammonium acetate method (Chapman 1965). Exchangeable bases (Na^+,K^+, Mg^{2+} and Ca^{2+}) were extracted by neutral 1 N NH_4Ac method (Thomas 1982). Exchangeable calcium and magnesium were measured by atomic absorption spectrophotometer while the exchangeable sodium and potassium were determined by flame photometer (Knudsen & Peterson 1982). Soil pH was measured potentiometrically in 1: 2.5 soil/water suspension and 1:2.5 soil/1 M KCl suspension. Organic carbon content was estimated by the wet combustion method of Walkley - Black (Nelson & Sommers 1982). Available phosphorus was extracted by Bray and Kurtz No. 1 Method (Bray & Kurtz 1945) and determined by a spectrophotometer based on the intensity of the blue colour developed by the ascorbic acid-ammonium molybdate complex (Murphy & Riley 1962) and modified by Watanabe and Olsen (1965). Kjeldahl total nitrogen was estimated

Table 1. Agro-ecological characteristics of sites

Eco-region	Altitutude and climte	Geology	Soils	Vegetation and land use
Kilimanjaro	altitude of 900 to 2300 metres above sea level rainfall of 1500 mm per annum, temperature varies with altititude: 15 to 28°C; dependable growing season of 3 to 5	quartzo-feldspathetic gneiss and granulites, horneblende and biotite gneisses, localized thick crystalline limestone masses	deep well drained dark reddish brown friable or firm clay loams and clays with strong structure; well developed profile, pH: 6 to 7.5, CEC: 20-45 cmol/kg, moderate to high fertility, Nitosols common	coffee and bananas plantations, forest patches remaining on steep non agricultural lands, wide range of annual crops legumes and vegetables including maize, french beans, sunflower
Tanga	altitude of 150 to 500 metre, rainfall of 1100 mm per annum, temperature of 20 to 30°C, dependable growing season of 4 to 4.5 months	danded gneiss with crystalline aluminnous gneiss on the ridge summits and limestone gneisse in the plains	deep dreined reddish sandy clays to clays, weak structure, low fertility ferralsols (occupy 60%) and moderate fertility Luvisols (occupy 40%)	open tree cover without interlaced canopies with grass and herb cover, main crops are sisal, maize coconut and citrus
Morogoro	altitude of 200 to 500 metres to rainfall of 600 to 1200 mm per annum, temperatures of 15 to 30°C, dependable growing season of 3 to 3.5 months	hornblende and biotite gneisses with abundant garnet in the Uluguru mountain range, un-identified sediments of Karoo age and Neogene	yellowish or reddish sandy clays to clays with subsoil acidity Acrisol-Ferralsols type), together with reddish friable clays (luvisols)	wooded grassland with canopy cover of less than 50%, maize, sisal and sunflower are the main crops

following the method developed by Bremner and Mulvaney (1982).

Based on soil profile morphological properties and soil physical and chemical characteristics, soils were classified using both the USDA system of soil classification (Soil Survey Staff 1992) and the FAO legend of the soil map of the world (FAO 1988) as shown in Table 2.

RESULTS AND DISCUSSION

The topsoil depths observed are shown in Table 3. A minimum topsoil depth of about 10 cm appears to be a characteristic of all three eco-regions. Soils with the deepest topsoil were found at Kilimanjaro eco-region. The topsoil in this region reaches a maximum of 40 cm. Top-soil depth decreased in thickness both at Tanga and Morogoro, but more at Morogoro. Based on several topsoil measurements in the different sites, a depth of 15 cm was chosen as the upper limit of the shallowest topsoil while 25 cm was considered to be the lower limit of what could be considered as deep topsoil. This criterion corresponds with the depth limits used to define certain epipedons (Soil Survey Staff 1992). The depth range between 15 and 25 cm was arbitrarily subdivided at an interval of 5 cm. Accordingly therefore this study proposes the classification of topsoil depth range encountered in the field into the following four classes: <15 cm (1), 16 - 20 cm (2), 21 - 25 cm (3), and > 25 cm (4). Topsoil classes can be linked with past erosion such that classes 1, 2, 3 and 4 represent severely eroded, moderately eroded, slightly eroded and least eroded phases (Table 4).

The depth classes are considered wide enough to exclude the mixing up of neighbouring classes. The choice of depth ranges and not discrete limits are intended to conform with the concept of a soil as a

Table 2. Classification of the Soils of the study sites

Eco-region	Site	USDA Soil classification system	FAO (1988) Soil classification
Kilimanjaro	Kirima-Boro	Paleustaff	Humic Nitisols
	Xeno Helena	Paleustaff	Humic Nitisols
Tanga	Mlingano 1	Tropeptic Haplustox	Rhodic Ferralsols
	Mlingano 2	Typic Rhodustalfs	Haplic Lixisol
Morogoro	Misufini 1	Lithic Eutrochrepts skelic phase	Eutric Cambisols
	Misufini 2	Typic Eutrochrepts	Chromic Cambisols
	Misufini 3	Rhodustalfs	Chromic Luvisols
	Mindu	Ultic Haplustalfs	Haplic alfisols

Table 3. Average soil depth in the erosion classes at the different sites

Site	Erosion class			
	Severe < 15 cm	Moderate 16-20 cm	Slight 21-25 cm	Least >25 cm
Kirima Boro	12.9	18.0	23.4	31.2
Xeno Helena	12.6	17.9	22.5	
Mlingano 1	13.8	18.0	22.7	27.9
Mlingano 2	11.7	17.3	22.3	
Misufini 1	11.6	17.7		
Misufini 3		17.5	23.7	25.9
Mindu	11.7	17.7	22.3	

Table 4. Some selected top-soil properties of the sites studied

Site	Silt %	Clay %	pH (H_2O)	O.C.%	N %	P mg/kg
Kirima Boro	26	44	7.0	2.4	0.21	38
Xeno Helena	22	34	6.0	2.0	0.14	7.6
Mlingano 1	8	66	6.6	2.7	0.22	4.0
Mlingano 2	8	44	6.5	2.3	0.19	4.0
Misufini 1	6	19	6.5	1.2	0.11	<1.0
Misufini 2	5	19	6.6	1.1	0.12	1.0
Misufini 3	3	21	6.3	1.0	0.12	1.0
Mindu	5	25	5.8	1.2	0.11	<1.0

continuum. However, the average depth classes (Table 3) could be used to define the central tendency for each class. These topsoil depth classes are considered to correspond to a residual effect of an undeterminable series of catastrophic events of which soil erosion predominated.

The use of the above defined classes and phases in association with crop yield has to take into account the inherent fertility of the soil as well as the impact of current climate on production. Where landscape position changes, it affects both crop yield and extent of erosion (Daniels et al. 1985; Stone et al. 1985). Its contribution has to be taken into account when evaluating impact of the erosion phases on crop yield.

Selected soil characteristics of the topsoil layer of the sites studied are shown in Table 4. Inter site difference are big for clay, silt, organic carbon, total nitrogen and available phosphorus. Kilimanjaro sites (Kirima-Boro and Xeno Helena) are by far higher in silt compared to other sites. Associated with the low chemical fertility of the Morogoro sites, are the low values of organic carbon, total nitrogen and available phosphorus. The low silt content in Morogoro sites may have an influence on the crop performance taking into account the low rainfall of this eco-region and particularly that of the Mindu site.

The subsoil characteristics of these soils do not differ appreciably from those of the topsoil except for a slight increase of CEC at Misufini 1 and 3, a slight decrease of CEC at Mlingano 1 and 2, (Tables 6 and 7) and decrease of both total nitrogen and in Morogoro soils (Tables 4 and 5). Other but similar differences include the content and distribution of exchangeable calcium and potassium in the topsoil and subsoil as shown in Table 6 and Table 7. The highest values of exchangeable potassium occurred in soils of Kilimanjaro both in the topsoil and subsoil layers. Subsoil values were nevertheless lowest at Misufini 3 and Mindu sites in Morogoro. The content of exchangeable calcium also varied among sites. It ranged from 6.7 to 14 cmol/kg in the topsoil of Kilimanjaro sites to 4 cmol/kg in the leached soils of Morogoro (Misufini 3 and Mindu). Exchangeable magnesium was second after calcium in abundance in all soils, both in the topsoil and subsoil. There were relatively low inter site differences with respect to the content of exchangeable magnesium.

Aune & Lal (1995) proposed critical values of some soil characteristics of tropical soils for maize crop. Accordingly,

Table 5. Some selected subsoil properties of the sites studied

Site	silt %	clay %	pH H_2O	O. C. %	N %	P mg/kg
Kirima Boro	22	56	6.6	0.8	0.11	29
XenoHelena	22	42	6.3	1.6	0.1	14
Mlingano 1	4	72	6.5	0.9	0.07	1
Mlingano 2	5	61	6.4	0.5	0.07	4
Misufini 1	7	25	7.0	0.5	0.07	<1
Misufini 2	42	6	6.3	0.7	0.08	<1
Misufini 3	3	30	6.6	0.6	0.07	<1
Mindu	5	35	5.8	0.5	0.08	<1

carbon content oscillate around the critical value. These are important factors to be taken into account when assessing the impact of erosion on yield since the more infertile a soil is the bigger will be the impact of erosion on its productivity.

Table 6. Cation exchange properties of the topsoil of the studied sites

	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	BS
			cmol/kg			%
Kirima Boro	14	2.9	3.9	0.5	ND	ND
Xeno Helena	6.7	1.6	4.3	0.2	ND	ND
Mlingano 1	9.8	3.4	1.3	0.6	15.7	96
Mlingano 2	9.6	2.7	0.8	0.6	14	98
Misufini 1	8.0	3.1	1.1	0.3	19.5	64
Misufini 2	6.0	2.3	1.2	0.2	15.5	62
Misufini 3	4.0	1.9	5.3	0.2	12.0	95
Mindu	4.0	2.7	1.2	0.1	9.6	83

Table 7. Cation exchange properties of the subsoil of the studied sites

Site	Ca^{2+}	Mg^{2+}	K^+	Na^+	CEC	BS
			cmol/kg			%
Kirima Boro	10.3	1.7	1.7	0.3	ND	ND
Xeno Helena	6.3	2.4	1.3	0.5	ND	ND
Mlingano 1	3.5	1.7	0.9	0.4	12.4	52
Mlingano 2	4.4	2.5	0.8	0.4	8.5	96
Misufini 1	20.0	3.3	0.4	0.3	25.7	93
Misufini 2	6.0	2.7	0.5	0.3	12.7	75
Misufini 3	4.0	3.4	0.5	0.3	13.2	83
Mindu	2.0	2.9	0.6	0.3	11.5	50

CONCLUSIONS

On the basis of soil morphological characteristics, different soil depth classes have been defined. These vary both among ecoregions and sites. Soils of Kilimanjaro and those of Morogoro constitute the extreme cases in terms of the depth of the topsoil. Kilimanjaro are the deepest followed by Tanga and eventually Morogoro. Deepest soils are associated with more favourable soil chemical properties compared to shallower soils. Both the agro- ecological and soil differences are important factors which could amplify or mask the impact of past erosion on crop productivity. Extensive testing of the established erosion classes is suggested.

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Impact of Past Soil Erosion on Land Productivity in Selected Ecological Regions in Tanzania

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The impact of past soil erosion was studied at seven locations in three distinctively different agroecological regions in Tanzania. The corresponding soils in each ecoregion were classified as follows: Chromic Cambisols, Chromic Luvisols and Haplic Alfisols in Morogoro, Rhodic Ferralsols and Haplic Lixisols in Tanga, and Humic Nitisols in Kilimanjaro. Soil morphological properties were used to determine the thickness of the top-soil (horizon Ap). The latter was in turn employed to distinguish different classes of past erosion as follows: <15 cm (severely eroded), 16-20 cm (moderately eroded), 21-25 cm (slightly eroded) and > 25 cm least eroded). Both maize (*Zea mays*) and cowpea (*Vigna ungiculata*) were planted in the different classes as test crops. The lowest yield was observed in the most eroded site in 6 of the 7 sites. The critical limit for top-soil depth with regard to crop productivity seemed to be approximately 20 cm at the Kilimanjaro and Tanga site, and somewhat higher at the Morogoro site. Yields were generally about 30 % higher in the least eroded classes compared to the most eroded class, but at one site this difference in yield was observed to be as high as 75%.

Key words: cowpea, maize, soil erosion, soil properties

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Soil erosion is a common feature in the tropical and sub tropical zones of Africa, Asia, Latin and South America. In Tanzania, accelerated soil erosion is a widely spread phenomenon which takes place in different forms and intensities affecting nearly all major landuse and soil types. Like in many other countries, erosion studies in Tanzania have been mainly concentrated on measurement of soil loss from agricultural lands (Temple, 1972; Ngatunga, et al. 1984).

Erosion studies in the last few decades heavily concentrated on soil mass movement or loss of topsoil layer. Such losses have been linked with the rate of soil formation to calculate soil loss tolerance, a criterion which has been described as lacking a research base (National Soil Erosion-Crop Productivity Research Planning Committee 1981).

Neither the economic consequences of soil erosion nor the impact of the process to crop production are sufficiently known in Tanzania and in the rest of the tropics. The extent of contribution of soil erosion to the low production of both food and cash crops is uncertain. According to Lal (1990) there is a disturbing degree of correspondence between the area affected by severe soil erosion and those prone to gross food deficit notably in Africa. Lal (1985) pointed out that one of the major knowledge gaps in understanding soil erosion is its monetary implications. He advocates that soil erosion and its effects must be expressed in monetary terms related to loss in productivity, environmental damage and damages to infrastructure and civil properties. The real impact of erosion is far greater than a simple loss of nutrients. According to Stockings (1986) organic matter losses and off-site costs in sedimentation are just a few among the major components which need to be taken into account when working out the cost due to soil erosion.

Several methodologies have been employed to study the soil erosion and crop productivity relationship. They include, among others, long-term agronomic experiments with known levels of soil erosion, laboratory and greenhouse studies, desurfacing experiments, crop productivity models, and assessment of soil properties through field surveys (Lal 1988).

While the desurfacing approach could serve as a quick means of data generation, there is a major shortcoming associated with this method. The reason is while erosion by water is selective in terms of the size of the particles which are washed away, desurfacing is not. Lal (1985) showed that natural erosion caused 16 times more decline in maize yield than that by equivalent depth removed artificially. Direct agronomic assessment of crop yields on land from which loss of surface soil has been assessed on field run-off plots is the most ideal approach to the problem (Lal 1988). However, this approach is expensive and lengthy so it may not be the appropriate source of data for the vast erosion stricken tropical zone.

The objective of this study was to work out field criterion for identifying and defining different degrees of past soil erosion, and use maize (*Zea mays*) and cowpea (*Vigna ungiculata*) as test crops to study the impact of past erosion on yield.

MATERIALS AND METHODS

This study was conducted in Kilimanjaro, Tanga and Morogoro regions in Tanzania. These regions represent three different agro-ecological zones and will be referred to as Kilimanjaro, Tanga and Morogoro ecozones in the rest of the text (Table 1). In Kilimanjaro two sites, namely Xeno Helena and Kirima-Boro were selected. In Tanga two sites, Mlingano 1 and 2, were chosen while in Morogoro four sites, Misufini 1, 2, and 3 and Mindu, were used for this work. However, the data on Misufini 2 are not presented in this paper. With an exception of the sites in Kilimanjaro, each site was characterised by a unique type of soil as indicated in Table 1. The Misufini sites were further differentiated on the basis of the depth to the gravel layer.

The choice of sites was done in such a manner as to include some of the important agroecological zones and soils of Tanzania. Details of the characteristics

Table 1. Classification of the soils of the study sites.

Eco-region	Site	USDA Soil classification system	FAO Soil classification
Kilimanjaro	Kirima-Boro	Not classified	Humic Nitisols
	Xeno Helena	Not classified	Humic Nitisols
Tanga	Mlingano 1	Rhodic Eustrox	Rhodic Ferralsols
	Mlingano 2	Typic Rhodustalfs	Haplic Lixisols
Morogoro	Misufini 1	Lithic Eutrochrepts skelic phase	Eutric Cambisols
	Misufini 2	Typic Eutrochrepts	Chromic Cambisols
	Misufini 3	Rhodustalfs	Chromic Luvisols
	Mindu	Ultic Haplustalfs	Haplic Alisols

of the ecozones are provided elsewhere (Kilasara et al. 1995).

Determination of different degrees of soil erosion was done by first conducting a very detailed topographic survey followed by a detailed soil survey. The topographic survey was conducted at a mapping scale of 1:100 with a contour interval of 5 cm. The ground surface conditions recorded were used together with the soil survey data to select the various soil erosion classes. The soil survey was conducted on mini-pits (0-50 cm deep) which were dug at a grid spacing of 5 m. The purpose of the survey was to differentiate the topsoil from the underlying subsoil on the basis of soil colour, texture, consistence and structure. The boundary between the topsoil and the subsoil was established and the depth from the soil surface to this boundary was taken to represent the depth of the topsoil or Ap horizon.

Based on the topsoil depth data from all the sites, four different classes of soil erosion were established. These classes were: < 15 cm (severely eroded), 16-20 (moderately eroded), 21-25 (slightly eroded) and > 25 cm (least eroded). These classes are referred to as erosion class 1, 2, 3 and 4, respectively.

Twelve plots of 5 x 5 m were selected for each erosion class. These were used for soil sampling, field physical measurements and for planting. Cowpea was used as a test crop in the short rain season (October-December) and maize (variety MTV-1) as test crop in the long-rain season (March to June). Cowpea was sown at a spacing of 50*15 cm and maize at 75*30 cm spacing. Biomass and grain yield data from both crops were collected. The cowpea crop was successful at Kilimanjaro and Tanga but it failed in Morogoro due to drought.

No fertilizer was applied to cowpea, but for maize both nitrogen and phosphorous were applied each at a rate of 40 kg ha-1. This amount was equivalent to half of the recommended rate of both nutrients in Tanzania. Data on biomass, grain yield and selected vegetative crop vigour parameters were collected.

The results were analyzed according to a one way analysis of variance, using the MSTAT package (Nissen et al. 1994).

RESULTS

Kilimanjaro

The yield data of maize crop for Kilimanjaro ecoregion is presented in Table 2. At the Kirima-Boro site, 4 different erosion classes were identified. There was only a minor difference in yield between the three least eroded classes, but a significant difference between these 3 classes and the most eroded class was observed. Yield of the three least eroded classes was on average 19% higher than that of the most eroded class. The trend in stover yield followed the same pattern as the grain yield. Yields were rather low when cowpea was used as a test crop at this site, being in average only 448 kg ha^{-1} and with an average harvest index as low as 17.5% (Table 3). As for maize, the yields were

Table 2. Effect of different degrees of past soil erosion on maize yield in Kilimanjaro ecoregion.

Site	Erosion class code	Grain yield (kg/ha)	Stover (t/ha)	Biomass (t/ha)	HI
Kirima-	1	2874	7.2	11.1	0.26
Boro	2	3343	8.1	11.6	0.27
	3	3521	8.2	12.7	0.28
	4	3409	7.4	11.7	0.29
	LSD5%	319	NS	NS	0.016
Xeno	1	2512	3.7	6.6	0.37
Helena	2	3626	5.3	9.6	0.37
	3	2997	4.8	8.5	0.35
	LSD5%	719	0.9	1.5	NS

NS = Non significant

Table 3. Effect of different degrees of past soil erosion on cowpeas yield in Kilimanjaro Ecoregion.

Site	Erosion class code	Grain yield (kg/ha)	Stover (tons/ha)	H.I.
Kirima-	1	497	3.5	0.12
Boro	2	615	3.8	0.14
	3	663	2.9	0.18
	4	668	3.1	0.18
	LSD5%	126	N.S.	N.S.
Xeno	1	902	3.0	0.23
Helena	2	1214	5.0	0.20
	3	1220	4.1	0.23
	LSD5%	240	1.6	NS

N.S = Non Significant

lowest in the most eroded classes. Yields were, on average 31% higher in the least eroded classes as compared to that in the most eroded class. However, no significant difference could be observed in biomass production between the erosion classes. The harvest index was therefore lower in the most eroded classes.

At Xeno Helena only three erosion classes were distinguished. At this site, the maize yield was lowest in the most eroded class. However, yields were higher in the moderately eroded class than in the slightly eroded class. Yield in the two least eroded classes was on average 32% higher than in the most eroded class. The same trend was observed in stover yield. When cowpea was used as a test crop, yield was 35% higher in the least eroded class than in the most eroded class. However, contrary to when maize was used as a test crop, no differences in yield were observed between the two least eroded classes.

Tanga

Maize yield at Mlingano 1 varied from 1299 kg/ha in the severely eroded class to 2061 and 2487 kg/ha in the moderately and slightly eroded classes, respectively (Table 4). This is equal to an increase of 75% from the most eroded class to the two least eroded classes. At Mlingano 2 the data on maize yield did not follow any consistent trend. The yield data of cowpea was obtained from Mlingano site 1 only (Table 4). Cowpea grain yield increased with decrease in the severity of past soil erosion from 1691 kg/ha in the severely eroded class to 2389 kg/ha in the slightly eroded class.

Morogoro

The maize grain yield data for the Morogoro ecoregion show a wide variation, both among sites and individual soil erosion classes (Table 5). In general, the sites at Misufini location had a relatively higher yield than that at Mindu. At

Table 4. Effect of different degrees of past soil erosion on maize and cowpeas yield in Tanga ecoregion.

Site	Erosion class code	Maize grain yield (kg/ha)	Cowpeas grain yield (kg/ha)
	1	1353	ND
Mlingano 1	2	992	ND
	3	1505	ND
	4	1364	ND
	LSD5%	352	NA
	1	1299	1691
Mlingano 2	2	2061	1712
	3	2487	2389
	LSD5%	593	558

ND = Not determined, NA = Not applicable, N.S.= Non Significant

Table 5. Effect of different degrees of past soil erosion on maize yield and selected vegetative parameters in Morogoro Ecoregion.

Site	Erosion class code	Grain yield (kg/ha)	Plant height (cm)	Number of plant leaves
Misufini 1	1	2476	100.8	12.2
	2	2899	122.3	11.8
	LSD5%	191	19.6	N.S.
	2	2373	116	11.4
Misufini 3	3	3535	132	12.9
	4	3547	125	13.0
	LSD5%	285	12.7	0.80
Mindu	1	2109		12.4
	2	2448		12.3
	3	2713		11.2
	LSD5%	126	NS	0.94

N.S.= non significant

Misufini 1, the maize grain yield in the severely eroded class was 2476 and that in the moderately eroded class was 2899 kg ha^{-1}. The maize plant height also varied significantly ($p<0.05$) between the two classes, the corresponding values being 100 and 122 cm for the severely and the moderately eroded classes, respectively.

The maize yields at the Misufini 3 site was relatively good with average yield being above 3000 kg ha^{-1}. A significant difference in yields were observed between the moderately eroded class and the remaining two classes with less soil erosion. Yields were 29% higher in the least eroded classes than in the moderately eroded class.

At Mindu, there was only a small difference between the yields among erosion classes, but as for the other sites yields were lowest in the most eroded class.

DISCUSSION

From the results it appears that top-soil depth can be used as a criteria for classifying the soil into different erosion classes. This confirms the findings of previous studies done under controlled conditions (Eck et al. 1965, Rehm 1978, Mbagwu et al. 1984). Yields were lowest in the most eroded class in 6 of the 7 soils examined. However, there were no significant differences between the remaining less eroded classes. It therefore appears that the relationship between top-soil depth and yield follows a parabolic function, where the effect of top-soil depth on productivity only becomes apparent when top-soil depth falls below a specific value (critical top-soil depth). The critical top-soil depth may be approximately 20 cm for the Lyamungo and Mlingano sites. Results of two locations at Morogoro indicated that the critical depth at this site is somewhat higher possibly being close to 25 cm. This higher critical depth at Morogoro might reflect the more unreliable rainfall at this site.

The highest yield was observed in the Kilimanjaro region. This can be related to a more reliable rainfall and a better soil fertility as compared to the other sites. Both Morogoro sites have lower levels of total nitrogen than other sites which make this soil more susceptible to erosion caused yield reduction.

The fact that the ranking of erosion classes was generally the same for both cowpea and maize suggest that the erosion classes do not differ in ability to release nitrogen, but is more related to other factors. This is because cowpea is known for fixing its own nitrogen.

At the Kirima-Boro site, it was observed that the harvest index was higher in the least eroded class than in the most eroded classes. This indicate that the cowpea was more exposed to a drought stress at the end of the rain season in the most eroded soils. It is therefore possible that the erosion has influenced the soil water holding capacity and/or the run-off characteristics of the soil.

The data show that it is possible to differentiate only two erosion classes at each site. However, this observation might be misleading when taken into consideration the concept of critical limits. This concept implies that the effect of soil erosion on productivity is observed only when top-soil depth falls below the critical level.

The effect of soil erosion on productivity observed in this study is difficult to compare with results from other studies because of differences in methodology. However, the result of this study demonstrate that there is no linear relationship between soil erosion and productivity. The critical limits for top-soil depth seem to be approximately 20 cm for Mlingano and Kilimanjaro sites and somewhat higher for the Morogoro site. Yields were typically about 30% higher in the least eroded classes than in the most eroded class. At one location this difference was 75%. These results correspond to some extent with other studies in Africa. Rehm (1978) measured a 50% drop in maize yield in Cameroon when 2.5 cm of the topsoil was removed artificially and virtually no crop when 7.5 cm was removed. In Nigeria, Lal (1976) recorded a 23% reduction of maize yield when 2.5 cm of topsoil was artificially removed. Data on reduction in yield due to natural soil erosion is very scanty. Mbagwu et al. (1984) reported a drop in yield of maize and cowpea in the Southern-Eastern of Nigeria which would not be effectively offset by application of different combinations of nitrogen and phosphorus.

Information on relationship between soil erosion and productivity is important in order to assess the economic consequences of soil erosion. Such information is of vital importance in land use planning. Further information is needed from more soil types and more ecoregions and the extent to which the soil management can offset the effect of soil erosion.

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Land has come back - lessons from a soil conservation project in Dodoma region of Tanzania

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Hifadhi Ardhi Dodoma (HADO) - Soil and Water Conservation in Dodoma Region -constitutes one of national projects of its own kind in Tanzania. The area in which the project operates i.e. Dodoma Region, is plagued with the worst example of soil erosion and degradation in Tanzania. Land is dissected by many wide and deep gullies as well as sand choked rivers. The situation is aggravated by deforestation that is taking place at the rate of 20,000 ha/year, overstocking, annual bushfires, faulty agricultural practices, population pressure as well as harsh environmental factors such as rainfall erosivity and soil erodibility. Losses in productive soil are enormous - denudation rates of 1 -2mm/year and erosion rates in the order of 55 tons/ha/year. In certain cases run off of up to 60% of total rainfall has been observed. The HADO project was launched by government of Tanzania in 1973 as an attempt to arrest this situation. Its activities vary from making contour bunds on uncultivated degraded lands, using crawler tractors and human labour, tree planting, farmland soil conservation, destocking, to protective as well as institutional measures. These efforts seem to pay dividends. Gullies are healing, rivers now follow narrower and or more defined water courses and vegetation is recovering and stabilizing sand fans. There is thus more land for cultivation. Farmers have constructed more than 650,000 metres of contour ridges during the last nine years to conserve soil and water on their farms. Other farmers, schools and women groups have started their own tree nurseries. Applied research on the development of zerograzing (mainly milk cows) in the destocked areas is already underway. The general feeling as expressed by the ordinary farmer is that "*Land Has Come Back*".

Keywords: bushfires, desctocking, land reclamation, population pressure, zero grazing

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INTRODUCTION

The apparent increase in soil erosion and degradation had prompted the British colonial government to establish a Soil Conservation Advisory Committee in 1930. Under the advice of this Committee the government adopted the policy of improving land use methods which included among others, reduction in number of livestock, ridge cultivation, contour banking of uncultivated land, gulley control, rotational grazing as well as depopulation. By 1953 some 2176 km of contour bands had been constructed on uncultivated land in the then Central Province (the present Dodoma and Singida regions). In Kondoa district where the menace of gulley erosion was (and still is) greatest, farmers were obliged to plant sisal around their farms.

Unfortunately these measures proved unpopular because orders, regulations and restrictions pertaining to soil conservation seemed to be applied only to indigenous Tanganyikans. All soil conservation measures which were regarded as part of colonial bondage were ignored (at least temporarily) after attainment of independence.

However, within the first decade of independence, all including the new government had awaken to the reality of the hazard posed by turning a blind eye to the imminent problem of soil erosion and degradation. On the advice of Central government, Kondoa District Council enacted a by - law in 1968 prohibiting grazing, cultivating, digging water channels and cutting down trees without permission in the badly eroded areas of Irangi Highlands now popularly known as the Kondoa Eroded Area (KEA). This proved inadequate as with time, and the government realised that something tangible needed to be done in an attempt to arrest a situation which seemed to be getting out of hand.

The first study on soil erosion and degradation in Dodoma region with special emphasis on Kondoa District was initiated by the Government in 1972. Recommendations of this study resulted in the launching of Hifadhi Ardhi Dodoma (HADO) in the fiscal year 1973/74. The overall goal of this project was and still is to prevent and arrest the advance of soil erosion and where technically and economically possible to reclaim the depleted land for productive use.

This paper presents the way the project has been implementing its activities, the problems faced and the achievements attained. It also presents the experiences gained and finally highlights the possible future direction.

PROJECT APPROACH

This section outlines the procedure of how the problem was implemented including the main project activities. It later presents the problems encountered during the different times of project implementation and closes the chapter by demonstrating some of the project achievements.

Project implementation

According to Mbegu (1988), the first ten years of HADO can be compared to a swimming student thrown into a swimming pool to learn "swimming by swimming".

The national leadership had wanted the HADO programme to be implemented by the Forest Division whose personnel's training traditionally concentrated on industrial/plantation forestry as opposed to environmental conservation that it was now called upon to practice. Further, at that time, there existed in Tanzania no other such project from which some lessons could be learnt.

During this period, activities that featured prominently were:

-Raising of tree seedlings, the bulk of which was used by the project itself and only about 24% of them were distributed to villagers, schools and institutions.

-Planting of trees as woodlots on uncultivated lands as well as on contour bunds.

-Construction of contour bunds using caterpillar tractors and hand labour on uncultivated lands.

Apart from distributing seedlings to villagers, schools and institutions, hardly anything was done to involve the local people in tackling the mammoth problem.

At the same time all these activities were scattered and in rare cases they complemented each other.

Experiences gained in the early stages of project implementation helped to shape activities. One example is the decision to destock the KEA in 1979 which was a result of observations made on the contour bunded areas which were closed for grazing.

Apart from maintaining the good gains of the first ten years the following years were remarkedly influenced by the contact made with the Regional Soil Conservation Unit, Nairobi, through seminars, workshops and tours. This phase is characterised by turning more attention to farmland conservation and involvement of people to ensure their cooperation and subsequent sustainability of the project itself.

Problems encountered

If some success by HADO has been recorded, it must be understood that hurdles have had to be crossed. According to Mbegu (1994) these hurdles included a well educated local gentleman holding a high post in government who was very opposed to the suggestion to close certain areas to grazing which were obviously overgrazed; a high ranking politician trying to attract votes at election time by promising to return livestock to a destocked area; a donor organisation enters into agreement with ministry and regional high level officials to re-introduce livestock in destocked areas at an arbitrary rate of ten cattle per family, probably unaware that in so doing they would be pouring in more than twice the number of animals originally evicted; local leadership remaining mute to the local people's actions which were opposed to the spirit of conservation and rehabilitation (e.g. illegal grazing) while the project staff was always pelted with accusations for mistreating "wananchi".

These were some of the problems encountered at HADO. Government bureaucracy also created several hurdles by not making timely decisions in disbursement of funds.

These institutional and political problems characterise projects like HADO and are not only the most pressing, but also most difficult to solve or deal with, since one is obliged to scrupulously observe government regulations and discipline. Some of these could be discussed at local meetings but basically it was the cultivation of a sense of independence and steadiness of the project staff that saved the day.

Other problems encountered in the project were as follows:

- Resistance at time of destocking. This was augmented by the critics argument that the move was depriving people from milk, manure and meat. Some prophets of doom even foretold of an imminent massive death rate of children because of malnutrition. This has never been reported by the Health Department. The health of children in the KEA still compares well with areas outside, presumably because alternative foods are available. Hopefully, the zero grazing exercise now in progress will solve the question of milk and manure and later on provide biogas.
- Bush fires are now a menace to natural vegetation that has mushroomed in the closed areas. This is a common phenomenon throughout Tanzania but rather new in the destocked areas which only fourteen years ago were devoid of such heavy vegetation cover. More embarrassing however, is the fact that this cover is probably the most important in checking run-off, trapping sediment, increasing infiltration and organic

matter content in the soil and thus preventing erosion.

- Encroachment into restricted areas as a result of fodder shortage in surrounding areas particularly during dry periods, and adverse climatic conditions.
- The impression of the vegetation cover to ordinary farmers is that the land has recovered, "Land Has Come Back" they say. They do not see the reason for not being allowed to revert to the former uses, such as, grazing.
- In dealing with contraveners of conservation laws, regulations and orders, certain law enforcing agents are either reluctant or just defiant.

In most cases it can be concluded that environmental education should not be directed towards ordinary farmers or the less educated only. There is still a long way to go before the seriousness of environmental issues are assimilated by our society in its entirety. Concerted efforts should make sure that the message about protecting and managing of our environment reaches each and every member of the society.

Achievements made

With all the problems mentioned, there is a lot on the positive side. Both tangible and intangible benefits have been realised as a result of activities of HADO project.

There is considerable vegetation recovery as part of ecological transformation due to ban on grazing. A change from formerly heavily browsed shrubs and desolated landscapes to impressive vistas with grass and vigorously sprouting shrubs. No doubt such vegetation reduces run-off and increases both infiltration and retention of water by the soil. Vegetation cover also traps sediment thereby minimizing reservoir and lake siltation.

Grass as thatching material is now readily available in the destocked areas, so that construction of more spacious gable roof houses is taking over from the "traditional" mud covered flat topped "tembe". Thatching grass is collected free of charge and if traded fetches Tshs 80 to Tshs 100 per headload. Thus it can be a source of income as well.

The fuelwood problem has started to ease off because of tree planting and regeneration of natural woody vegetation. It is not only that fuelwood is now cheaply available at short distances, but also women's precious time and energy spent on fuelwood collection are greatly minimized, and spared for other development activities.

Farmers have adopted tree planting in various forms and are getting their requirements of fuelwood and poles by pruning, looping and polarding. One pole at Haubi (Kondoa) and Ikowa (Dodoma Rural) can fetch Tshs. 50.

As a result of destocking and subsequent ecological transformation, there is obvious increase in arable land which would have otherwise been used for grazing. Reclaimed areas and stabilized sand rivers are now put under agricultural expansion and horticultural activities, such as, growing of tomatoes, vegetables, sweet potatoes and sugar cane. Income from these activities goes a long way to improve the standard of living of the target group.

From research and training point of view, HADO has provided unique opportunities. There are eight research projects within the "Man-Land Interrelationship in Semi-Arid Tanzania", a multidisciplinary research programme.

Introduction of zero grazing in KEA has shown positive effects and is considered as a good start towards improving stock quality. Up to the year 1992/93 there were already 356 zero grazing units in KEA alone.

EXPERIENCES LEARNT AND THE FUTURE APPROACH

This section presents a general view of the experiences learnt during the project implementation phase. It also presents proposals for future project approach.

Experiences learnt

As mentioned earlier, HADO project has gone through a sort of metamorphosis which could be emulated from elsewhere in Tanzania. A number of lessons have inevitably been learnt in the process. These can be summarised as follows:

- Given strong political will, man is capable of reversing soil erosion and degradation processes.

- It should be realised that man occupies the central position in the environmental degradation processes. Therefore, he must be called upon to "swallow a bitter pill" in order to change the trend, for his own benefit and that of his descendants.

-The rapid regeneration of vegetation after closing KEA and Mvumi division tog grazing is obvious proof of detrimental effect of overstocking to the vegetation and soil.

-Large gullies can be prevented from growing in both width and depth by vegetative means and rendered productive. They can be planted with elephant grass to be used as fodder or sugar cane for food, fodder and fuelwood.

-In the course of time, the need for interdisciplinarity approach to soil conservation presented itself clearly. The project worked towards this goal in the last ten years through organization of several joint workshops, seminars, tours and excursions. But little was realised because of what could be termed as "too much professionalism". Other disciplines felt as if they were belittled or pushed around by HADO. Could an organization be formed to solve this problem?

-Local detractive interference in the project is quite visible especially at election time to solicit votes. It can counter the project efforts to enforce agreed laws and regulations to the point of even jeopardising workers lives. Such conduct is making opposition towards government policy and should be prohibited.

-Since projects like HADO may not be popular to the local leadership initially, or at certain times during their operation (e.g. election time), they are better run nationally. Otherwise there is a big risk that project leadership might bow to the local political or government pressure at the expense of the well being of the project. Moreover, it is likely that they would not receive due attention at the local level, because they are not income generating.

Future approach

The proposed future project strategy is aiming at focusing efforts in specific selected areas. This is the catchment approach advocated in other projects. All project activities will be done in that area.

The main purpose of having such areas are both for the purpose of the project success and as a demonstration to the farmers. This, therefore, means that the following should be the objective of the concentration area approach:

- To have a better project impact
- To have a good demonstration effect since all the measures are applied in the same area
- To ensure better project resource allocation

- To make it easier to implement, monitor and evaluate the project

Since all the activities will be done in one area it is necessary to have multi-disciplinary teams. These are important in the development of the land in question. Thus emphasis needs to be laid on inter-sectoral team for solving farmers problems and to improve conservation in the future.

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Agroforestry in the Southern Highlands of Tanzania

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Kamasho, J.A. Agroforestry in Southern Highlands of Tanzania. Norwegian Journal of Agricultural Sciences. Supplement No. 21: 87-92. ISSN 0802-1600.

A maize-Leucaena leucocephala alley cropping system was studied on Uyole and Ismani soils in Southern Highlands of Tanzania from 1981 to date. In this study maize was grown in 4m width alleys between leucaena hedge rows. The application of 5 tons mulch/ha was able to increase yield compared to control without mulch at both locations. There was a leucaena/maize competition. Maize grown less than 1 metre away from leucaena rows was affected and yield reduced by nearly twenty percent. The annual mulch production was approximately 2100 kg dry matter/ha and wood production after 9 years for Uyole and 6 years for Ismani was respectively 45 and 22 m^3 stacked volume/ha.

Key words: alley cropping, competition, leucaena leucocephala, maize, wood production.

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Demographic pressure in Southern Highlands of Tanzania call for a special attention on soil fertility to ensure sustained food production. Soils get depleted (in nutrients) due to accelerating deforestation, intensive agriculture, overgrazing and excessive use of fire in farm and rangeland.

The common practise in some parts of Southern Highlands, especially Sumbawanga, is "Chitemene", which involves burning of wood and other vegetation to create ash. This burning adds nutrients to the soil, reduces weed infestation and tends to reduce soil acidity for a few years. However, with the rapid increase in population, deforestation has increased, leaving the land virtually bare. This has caused an increasing shortage of firewood and roofing material.

There is an urgent need to replace the Chitemene system with a more productive, stable and less destructive one which can also sustain a reasonable yield for a longer period of time. Previous attempts have emphasized the use of herbaceous leguminous species which are effective for soil fertility restoration including erosion control, quick growth and easy to establish. Their usage has not become popular because of extra cost, effort to establishment, lower biomass, lower nutrient contribution and their inability to incorporate large quantities of organic matter as green manure with available tools.

Farmers in the Southern Highlands, especially those with large farms are aware of the effectiveness of *Albizzia maranguasis* in coffee and tea plantation as windbreak and shade, and as a mulch producer which can improve soil fertility. Other species such as *Sesbania grandiflora*, *Leucaena leucocephala* and *Acacia albida* are also very popular. These species are all trees or giant shrubs which in addition to soil fertility regeneration, are also source of firewood, staking materials, mulch and animal foods.

As part of efforts to improve the above described system, investigations were carried out in the Southern Highlands to meet the following objectives:

i) to assess the effectiveness of the systems in terms of crop yield
ii) to determine the effect of Leucaena competition on maize yield;
iii) to determine the amount of firewood, biomass a tree can contribute

MATERIALS AND METHODS

The field trials were carried out on a volcanic soils of Uyole (Haplic phaozems, FAO legend Romblow-Pearse and Kamasho 1984) and on deep red soils of Ismani in Iringa (Euric Fluvisols, FAO legend AGRAR and Hydsrotechnic (GMRH 1986) (Table 1).

The Uyole site has a sub-humid climate with a rainfall of 1000-1400mm. Ismani in Iringa has a semi-arid climate with rainfall below 750mm (EAMD 1980).

Scarified seeds of Leucaena leucocephala variety K-28 seedlings were planted at 0.5m within rows and 4 meter between rows in April 1981. The entire experimental area consists of six leucaena rows giving four alleys each 79m long. From April 1981 to November 1983 during leucaena establishment, the alleys were under natural grass fallow.

The first maize cropping in the alleys was done during the 1983/84 season. The field design was a split-plot with four replications; mulch treatment on main plots and fertiliser N (Calcium ammonium nitrate) levels on sub-plots. Randomisation was not complete as plots receiving 5 t mulch/ha was established next to the block with leucaena hedges.

The treatments were as follows

Mulch treatments (annual rates):	Fertilizer treatments (annual rates):
1. Leucaena alleys. No mulch	1.0 kg N/ha
2. Leucaena alleys. 2.5 tons fresh mulch/ha	2.30 kg N/ha
3. No leucaena alleys. 5 ton fresh mulch/ha	3.60 kg N/ha

Table 1. Selected properties of the experimental soils

Location	Parent material	Sub-group	pH	Organic carbon %	Ca me/100 g	Mg me/100 g
Uyole	Vulcanic ash over gneis	Haplic phaozems	5.9	2.8	6.3	1.1
Ismani	Mafic rocs	Eutric fluvisols	6.9	1.7	5.5	1.4

Yields in treatment with leucaena alleys was corrected by a factor of 0.72 in order to adjust for land occupied by alleys.

The alley crop was maize, a common food crop in the Southern Highlands of Tanzania. Hybrid variety H6302 commonly grown by farmers in Mbeya, and Kilima variety grown by farmers in Ismani Iringa Region were planted. The maize seeds were planted at spacing of 60 x 75 cm three seeds per hole and then later on thinned to two plant per hill two weeks after germination.

The hedge trees were pruned at 2 meter height in late 1982 leaving one shoot to grow and the total biomass weighed. This was repeated two times at two months interval per growing season for the nine years of study. In the ninth year the whole stem was cut and biomass assessed.

During harvesting maize rows close to leucaena hedges were weighed separately in order to assess the effect of shading and competition. Sampling was done at 0.5, 1.25, and 2.0 m (three rows at spacing of 0.75 m) from the leucaena rows. Maize grain yield was expressed at 12% moisture content. After the ninth year, the height of leucaena trees were measured. For stem girth, a circumference of each tree (ten trees for each hedge) was assessed using a measuring tape. Total biomass (stem, branches and leaves) were also obtained and expressed as tons/ha. For the wood, each part was cut at a length of 1 meter. This was expressed in terms of stacked volume/ha.

RESULTS AND DISCUSSION

Crop performance

The effect of mulch and nitrogen application on maize yield at Uyole is presented as mean yields for a 11 year period (Table 2). The highest yield was obtained where 5 ton mulch/ha was applied. Yields were only slightly higher in the treatment which received 2.5 ton mulch/ha compared to where no mulch was applied. An application of 60 kg fertiliser N/ha increased yield by approximately 50% compared to control. There was also a interaction between mulch application and fertiliser nitrogen. The effect of mulch was more pronounced where fertiliser N was given indicating a synergetic effect between the two factors.

The effect of mulch application was more pronounced at Ismani compared to at Uyole (Table 3). An application of 5 ton mulch/ha more than doubled average yield compared to control treatment. This happened despite that the effect of fertilizer nitrogen was less apparent than at Uyole. This might indicate that there has been a general improvement in che-

Table 2. Average mean yield for 11 years at Uyole (uncorrected yield in paranthesis)

	0 kg N/ha	30 kg N/ha	60 kg N/ha	Mean
0 ton mulch/ha	1589 (2205)	2191 (3041)	2271 (3152)	2017 (2799)
2.5 ton mulch/ha	1621 (2249)	2109 (2927)	2693 (3737)	2141 (2971)
5.0 ton mulch/ha	2852	3847	4517	3739
Mean	2020	2761	3161	

SE mulch=51.0 SE nitrogen=40.3, Interaction N*mulch $P<0.001$

Table 3. Average mean yield for 7 years at Ismani. (uncorrected yield in paranthesis)

	0 kg N/ha	30 kg N/ha	60 kg N/ha	Mean
0 ton mulch/ha	928 (1288)	1395 (1936)	1669 (2316)	1331 (1847)
2.5 ton mulch/ha	1707 (2369)	1798 (2495)	2184 (3031)	1896 (2631)
5.0 ton mulch/ha	2884	3391	3667	3314
Mean	1840	2194	2507	

SE mulch=54.2 SE nitrogen=49.4, Interaction mulch*nitrogen=n.s.

mical and physical properties of the soil which is not directly related to addition of nitrogen through the mulch. At this site there was no interaction between mulch and nitrogen.

Results from other agroforestry experiments have given contrasting results. Lal (1989) observed a decrease in yield while others obtained an increase in yield up to 70% (O'Sullivan 1985, Watson and Laguihou 1985).

Leucaena/maize competition is shown in Table 4. Maize grain yield from lines adjacent to leucaena was low, especially where higher rates of nitrogen were applied. Where 60 kg N/ha was applied, rows close to leucaena (0.5m) gave 2 t/ha while rows far away (2.0m) gave 4-4.8 t/ha. It thus appears that competition for light, moisture, and nutrients could be affecting yield of adjacent maize rows. This has also been pointed out by Agboola (1975), Brewbaker & Hutton (1979), Kang & Wilson (1981), and Wilson (1990) among others. These authors indicated that the food crop should be distant by more than 1 meter from the hedge. In addition, experiments conducted by Tropsoil (1987) showed that crop yields tend to increase with increasing spacing between rows of trees, though at the expense of the amount of mulch obtained. Szott et al. (1991) pointed out that in alley cropping, the associated crops were severely affected by root competition from hedgerows. His results and of others has caused alley cropping in tropics not to be conclusive. There is a need to sort out the manner by which the competition is enhanced by further research work.

Table 4. The effect of distance from Leaucaena hedge rows (m) on maize grain yield tonn/ha

	Uyole			Ismani		
	0.5 m	1.25 m	2.0 m	0.5 m	1.25 m	2.0 m
0 kg N/ha	1.80	2.50	2.80	1.89	2.24	2.71
30 kg N/ha	2.20	3.50	3.99	2.43	3.73	4.20
60 kg N/ha	2.30	3.80	4.80	2.57	4.08	4.32
Mean	2.10	3.27	3.86	2.30	3.35	3.74

$LSD_{5\%}$-Uyole=0.71 $LSD_{5\%}$-Ismani=1.04

Tree performance

Leucaena performance for the first year was rather poor. The leaves were chlorotic and the trees showed a slow growth. It took more than a year before the plants showed faster growth and for the chlorosis to gradually disappear. Similar observations were noted by Kang et al. (1981). They attributed these to low nitrogen-levels (Table 1) and slow infestation by indigenous rhizobium which were inefficient in causing nodulation. The plants grown here could have been affected by low N supply as there was no leucaena planted before, hence the population of appropriate rhizobium could have been low.

The first pruning yielded 3.1 t/ha of fresh tops equivalent to 0.96 ton dry matter. Subsequent pruning in the same first year gave 1.8 and 2.2 t/ha. The mean annual mulch production for the nine years of the study was 7 t/ha for Uyole and Ismani was 4 t/ha (Table 5). Further examination of the results shows that under Uyole conditions leucaena could achieve a height of 3-6 m and circumference of a stem in a range of 15 - 17 cm and wood yield after 9 years measures as stacked volume was 45 m^3/ha. For Ismani the height was 3-4m, stem girth 7-40 cm and wood yield after 6 years expressed in stacked volume was 22 m^3/ha (Table 5). These results are in good agreement with the observation made by Guevara (1976) that leucaena had ability to withstand frequent prunings, quick growth, thereby creating enough biomass for mulch and enough firewood to reduce energy crisis.

The results further suggest the potential of Leucaena as an alternative to the current system in Southern Highlands of Tanzania as it provides a substantial amount of wood materials. These wood material could be used for staking tomatoes or creeping beans and at the same time provide firewood. The stem girth of Leucaena also indicates that it can be used as a roofing material, especially for grass thatchedhouses.

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Table 5. Leucaena performance at Uyole and Ismani respectively 9 and 6 years after establishement.

Site	Height m	Stem girth (cm)	Mulch t/ha (annual prod.)	Wood, stacked volume m^3/ha
Uyole 9 years	3-6	15-70	7	45
Ismani 6 years	3-4	7-40	4	22

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Effect of green manuring and rotations on maize yield in the Southern Highlands of Tanzania

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Short term and long term trials involving crop rotations and green manuring were initiated at MARTI-Uyole and replicated at various sites in the Southern Highlands of Tanzania to determine their effect on soil fertility and maize grain yield. Results showed that the yield of maize grown after Crotalaria treated in various ways (whole plant incorporated, tops removed or stover incorporated) was significantly higher than that under control (over 100% increase). The effect of the green manuring was, however, only marked in the first season. Yield dropped in the following season if no manures were incorporated. Crop rotations involving beans, lupines and Crotalaria had a significant effect on increasing maize yields as shown by a 10 year trial at Mbozi Maize Farms Ltd. One year fallow was too short to have any effect on soil fertility and maize yield. It was concluded that the cropping systems have a potential for sustaining crop yields alone or with minimum external fertilization and that farmers should be encouraged to incorporate such alternatives in their farming system.

Key word: crop rotation, Crotalaria, green manuring, lupines, nitrogen

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Sustainability has of recent become one of the major targets in farming systems and farming systems research. Intercropping, alley cropping, green manuring and crop rotations involving legumes and fallow are some of the systems with potentials of sustainability. Sustainability in a farming system is characterised by a high efficiency of internal use of resources (Ingram & Swift 1989). This is possible through addition and conservation of soil organic matter and efficient nutrient cycling. This is more easily obtainable under natural ecosystems. It is more difficult to achieve this under agricultural system as nutrients are removed from this system with harvest product. Although it is possible to supplement soil nutrients through addition of inorganic fertilizers, such interventions by small scale farmers is always difficult given the unavailability on time and the ever rising fertilizer prices. It is for these reasons that the three systems: alley cropping, green manuring and crop rotations studies have been undertaken in the Southern Highlands to assess their contribution to soil organic matter and sustainability of crop production.

Although the findings of the rotations and green manure studies are relevant to large scale farmers in the Southern Highlands, the target group has been the low and medium input farmers who constitute the majority.

Green manuring refers to turning under any green or immature crop in order to add organic matter into the soil. The best crops for green manuring are those of leguminous type, such as, beans, cowpeas, soybeans etc. However, given the economic importance of such crops, it is almost impossible to convince a small farmer to grow them and then plough under just for the purpose of enriching the soil. An alternative plant called "marejea" - Crotalaria sp. offers a possibility for inclusion in the farming system as green manure. The potential of Crotalaria as green manure was studied in on short term- and in one long-term study.

The objectives of this studies were:

- to investigate the effect of soil incorporation of different parts of Crotalaria on maize yield
- to study the effect beyond one year of Crotalaria incorporation on maize yield
- to determine the supplemental N needed when Crotalaria is used as green manure.

Rotations between maize and leguminous plants were also tested in an other study. The objective was to study the effect of preceding leguminous species on maize yield.

MATERIALS AND METHODS

Green manuring trials

Short term study

The effect of *Crotalaria Zanziberica* (marejea) as a green manure on the yield of maize was studied in the early eighties at three locations in the Southern Highlands. The three sites, representing different ecological zones were Uyole Mbeya (1800m asl), Mbimba (1500 m asl) and Suluti (900m asl).

The trial was laid out in a split plot design replicated four times. The green manuring treatments in the main plots were as follows: maize after maize (no green manure) (1), maize planted after Crotalaria where above ground parts of Crotalaria were cut and removed from the field (2), and maize planted after Crotalaria where above ground Crotalaria parts where were ploughed under as green manure (3). Nitrogen at various rates (0, 40, 80, 120 and 160 kg/ha) were tested in the subplots.

Long term study

This study is a follow up of the previous one. This was necessitated by the fact that in the earlier trial, the effect of using Crotalaria as green manure was measured in terms of maize yields only. Also because the study time was short, long term soil changes and trends in yields could not be established.

The experiments were conducted at five different sites: Uyole, Mbimba, Ismani, Suluti and Nkundi commencing in 1988/89 (Nkundi 1992/93). In the first year, the trial was established by seeding Crotalaria at 20 kg /ha in the subplots. The experimental design was a split plot, main plots being fertiliser treatments and subplots being green manure treatments. The two main blocks included a no fertilized block and a fertilized block at 75 kg N/ha, split applied at planting and at 80 cm height of the crop. Phosphorus was also applied at 20 kg P/ha in this block. The green manure treatments on main plots were as follows: maize monocropping (1), Crotalaria aboveground parts ploughed under at 50% flowering (2), Crotalaria seed is harvested and the remaining stover is incorporated (3), Crotalaria harvested at 50% flowering and aboveground parts removed (4). Entry 3 simulates a situation where a farmer may opt to feed the tops to his livestock. Crotalaria dry matter is determined by taking plant samples from 1 m^2, dried (sun dried or by oven where available) and weighed.

Crop rotation

In order to assess the effect on maize yield of various rotations under Southern Highlands conditions, a long term trial was initiated in the 1983/84 season at Mbozi Maize Farms Ltd, in Mbeya Region. The rotation sequence including details of the treatments is shown in Table 1.

Crotalaria entries were not fertilized while beans received 40 kg N/ha and 40 kg P/ha. Maize grown continuously (no rotation) or after fallow received 120 kg N and 40 kg P/ha. However, when planted after a legume only 75 kg N/ha was applied. Crotalaria and lupine were planted early in the season, while beans were planted as a mid season crop. Incorporation of Crotalaria and lupine was at 50% flowering. In the 1989/90 and 1990/91 seasons no crop was planted. In 1991/92 season maize H6302 was planted in all entries fertilized with half the recommended N rate (75 kg N/ha) plus 40 kg P/ha. In 1992/93 Crotalaria, beans and lupine were again planted in the rotation.

RESULTS AND DISCUSSION

Green manuring

Short term study

Highly significant yield differences ($P < 0.01$) associated with use of Crotalaria as green manure were obtained (Fig. 1). Compared to the treatments without Crotalaria and fertilizer, mean yield increased by 2, 5, 7 times higher at Suluti, Uyole and Mbimba respectively in the

Table 1. Crop rotations from year 1983 to 1994

Rot	84	85	86	87	88	89	90	91	92	93	94
1	M	M	M	M	M	M	F	F	M	M	M
2	M	C	M	C	M	M	F	F	M	C	M
3	C	M	M	C	M	M	F	F	M	C	M
4	M	C	M	C	M	M	F	F	M	C	M
5	M	B	M	B	M	M	F	F	M	B	M
6	M	M	B	M	M	M	F	F	M	B	M
7	M	M	F	M	M	M	F	F	M	F	M
8	L	M	M	L	M	M	F	F	M	L	M

(1) maize grown on same plot every year
(2) maize alternated yearly with Crotalaria left to maturity, stover incorporated
(3) Crotalaria ploughed under bi-annually followed by two years of maize
(4) Crotalaria ploughed under annually, followed by one year maize
(5) maize rotated with beans yearly
(6) maize rotated with beans bi-annually
(7) two years maize followed by one year fallow
(8) two years maize then lupines as green manure incorporated at 50% flowering.

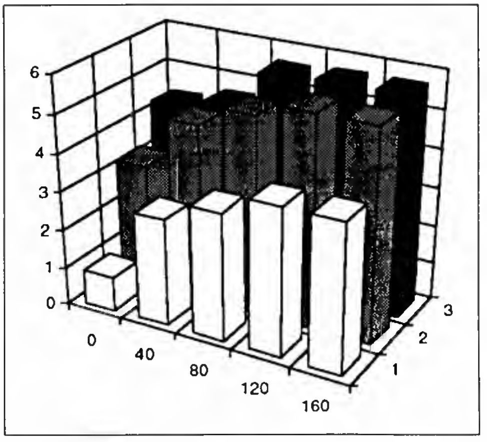

Figure 1. Combined result from 3 location on the effect of fertiliser and green manure on maize yield (1 season). Green manuring treatments were as follows: 1=maize monocropping, 2=Crotalaria and aboveground parts removed, followed by maize, 3, Crotalaria ploughed under, then maize.

first season. In the following season, maize yield dropped significantly indicating a low residual effect of the green manure.

Crotalaria in rotation with maize showed a mean nitrogen effect corresponding to about 80 kg N/ha when cut and removed, and about 120-160 kg N/ha when ploughed under in the first year. Similar results have been noted elsewhere. Reddy et al. (1986) in the USA investigated nitrogen production of various legumes and the effects on succeeding crop yields on a sandy coastal plain soil poor in nitrogen. They found out that Crotalaria produced 170 kg N/ha and that the yield of cereals (maize, wheat) planted in the succeeding season after the legume was chopped and rototilled into the soil was significantly higher than the control. Wangari (1994) studying the decomposition rate of Crotalaria ochroleuca and Leucaena leucocephala in a green house experiment at Morogoro found out that 70% of the green manures had decomposed after twelve weeks of incubation. This result explains why there is very limited residual effect of green manure application two years after incorporation. This is also supported by Singh (1974) quoting earlier reviews by Scherbatoff and Joffe (1955) that under tropical climates green manuring benefits only one following crop.

It was concluded that although soil incorporation of the tops and roots was better than incorporating roots only, both practices require yearly repetition in order to assure a stable supply from decomposing residues.

Long term study

Combined results for 3 years and 3 sites are shown in Figure 2. Maize yield was consistently higher where green manure was used irrespective of the way Crotalaria was treated compared to the continuous maize plot (Fig 2). However, incorporation of the above ground parts was superior to incorporation of roots

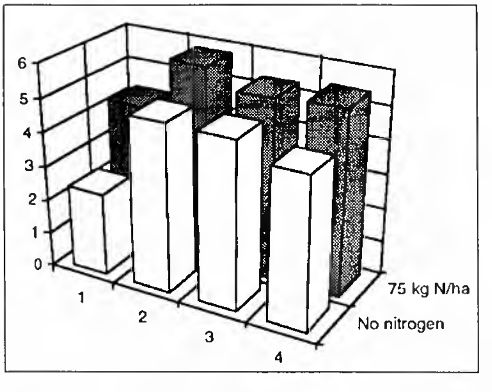

Figure 2. Combined result from 3 location and three years on the effect of fertilixer and green manure on maize yields. Green manuring treatments: 1=The green manure treatments on main plots were as follows: 1=maize monocropping, 2=Crotalaria aboveground parts ploughed under at 50% flowering, 3=Crotalaria seed is harvested and the remaining stover is incorporated, 4=Crotalaria harvested at 50% flowering and aboveground parts removed.

only as shown by the higher yields. This can be explained by the higher biomass and amount of nitrogen applied when the above ground part is incorporated. Crotalaria was more efficient in raising maize yield when no Crotalaria was incorporated , but even at a fertilizer rate of 160 kg N/ha there was an effect of crotolaria incorporation on yield. This indicated that there was an additional benefit of manure incorporation in addition to N supplement.

Crop rotations

Grain yield differences attributed to the various rotations were statistically significant at 5% level of probability for three consecutive seasons in which maize was harvested from all plots (Table 2). The conclusion drawn from the study is mainly based on the finding from the 1988 and 1989 seasons. In the 1988 season, yields were lowest in plots having maize as preceding crop. Maize yields were about 3 tonnes higher in plots having Crotalaria as a preceding crop compared to plots under continuous maize cultivation. Results from 1985 and 1988 season seem to indicate that beans and lupine used as preceding crop are less effective in raising maize yield compared to Crotalaria. As in the green manuring study, the effect of Crotalaria on maize yield seemed to last for one year only as plots having Crotalaria as a green manure in 1987 did not differ much from the plot under continuos cultivation in 1989. Two years of fallow (1990 and 1991) was not sufficient to improve fertility of the soil, suggesting that a longer fallow period is required.

CONCLUSIONS

Crotalaria was found to be a promising green manure crop as it supplies nitrogen to succeeding crop and provides animal feed. Benefits in terms of increased maize yield without or with minimum supplemental N have amply been demonstrated using Crotalaria as green manure or in rotation, including other legumes such as beans and lupines. It is always argued that green manuring has no benefit because nothing is harvested from that piece of land during the season. Planned properly however, this can be avoided. A farmer should not necessarily put the whole of his plot under green manuring in a season. Rather he should be encouraged to spare only a small portion for green manuring each season and then rotate in another portion in the following season.

Table 2. Maize yield trends (t/ha) at Mbozi Maize Farms

Rot	84	85	86	87	88	89	90	91	92
1	5.7	6.1	6.2	6.6	5.6	6.0	--	--	5.4
2	5.3	-	7.3	-	7.6	5.2	--	--	3.7
3	-	7.8	3.8	-	8.2	6.2	--	--	4.9
4	5.3	-	7.6	-	8.7	6.9	--	--	4.4
5	5.0	-	7.2	-	6.0	4.8	--	--	4.2
6	4.8	4.6	-	8.2	5.3	3.9	--	--	4.3
7	5.7	5.9	-	6.2	5.5	4.5	--	--	4.3
8	-	6.5	2.4	-	6.9	3.6	--	--	3.1

Alternatively, since many farmers keep livestock, the fodder from Crotalaria can be harvested and fed to the animals. The plot can then be used to plant a mid-season crop such as wheat or Irish potatoes. The crops will benefit from the nitrogen fixed by the roots. We have to bear in mind that farmers will be prepared to adopt organic fertilizing practices only if the ratio of perceived costs to benefits is favourable.

Another issue argued is that green manuring involves extra work for incorporating the green biomass into the soil using hand tools. This task can be made simple by using the normal ox-plough commonly employed for land preparation by many farmers in the Southern Highlands. With encouragement, they can opt for the technology. A number of projects are in operation in the Southern Highlands promoting use of ox-power, such as Mbeya oxenization project, Agricultural Development Program Mbozi, MARTI Uyole.

Both green manuring and crop rotations have a potential to contribute to sustained crop production if farmers adopt the cropping systems in a proper way.

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Towards Improving Soil Productivity by Sunnhemp (*Crotolaria Ochroleuca*) in the Highlands of Kilimanjaro in Northern Tanzania

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Sunnhemp *(Crotalaria ochroleuca)* was evaluated as a green manure crop grown in the short rain season at three different locations in the Kilimanjaro region of Tanzania. The experimental design was split plot. Nitrogen was applied at a rate of 0, 50 and 100 kg/ha in main plots corresponding to nil (N0), half (N1) and full dose (N2) of the recommended N fertilizer for maize in the area. The sunnhemp treatments were in sub-plots were as follows: absence of sunnhemp (S0), sunnhemp bottoms ploughed under and tops cut for forage (S1), and sunnhemp plant ploughed under (S2). Maize was used as a test crop in the long rain season. Sunnhemp treatment S1 gave yield equivalent to S2 treatment under a situation of no water stress. Yields were significantly higher than in control treatment without sunnhemp. However, under water stress, S2 treatment outyielded the S1 treatments. It appeared that the S2 treatment corresponded to fertiliser application equivalent to 100 kg N/ha and S1 treatment corresponded to fertiliser application equivalent to 50 kg N/ha. When only the bottom above ground part is incorporated into the soil (S1 treatment), 3.2 ton dry matter of sunnhemp/ha was in average for three sites available as animal feed. Considering shortage of animal feed and grain food in the region, this practice seems feasible. It offers an integrated and sustainable nutrient supply system over the on-going exploitive system of "cut and take all" from the maize fields.

Key words: Animal feed production, crotolaria ochroleuca, green manuring, nitrogen

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Kilimanjaro region covers an area of 13209 km^2 and supports a population of 84 (1988 Census) people per km^2; one of the highest in Tanzania. Annual rainfall varies from 600 mm to 1700 mm falling in two main seasons; the long rains from March to June and short rains from November to December. Maize and beans are grown for food in the long rains, but due to increasing unreliability of short rains, hardly any crop is grown in the short rains. As a result of land scarcity, farmers have resorted to extend crop cultivation on both marginal flat and sloping land. In the latter case, erosion is most common and disastrous. Majority of farmers practice exploitive agriculture on arable land. Cereals and legumes are continuously produced, and the whole above ground biomass is removed after harvest in form of grain for human food and stover for use as animal feed or bedding with no return to land. The farm yard manure is often used on coffee/banana land and vegetable production.

Besides exhausting the soil of nutrients, this practice leaves the soil bare which in turn permits increased evaporation, and exposes the soil to further erosion. It is therefore very likely that the cultivated soil of the Kilimanjaro region is being degraded. This is supported by declining crop yields often observed on unfertilized land. Annual rates of nutrient depletion in East Africa are estimated to be 30 kg N, 4 kg P and 25 kg K/ha removed (Stoorvogel & Smaling 1990).

Due to the prevailing economic situation which hardly permits use of fertilizer inputs, increased food production in this region has to rely on utilisation of organic material with the potential to control erosion, maintain organic matter, and promote nutrient recycling in combination with inorganic fertilizer. This strategy will ensure adequate and integrated nutrient supply system at the lowest cost possible.

Farmers in the Southern Highlands of Tanzania have demonstrated the us of sunnhemp (*Crotalaria ochroleuca*), popularly known as Marejea, as a green manure (Gerold 1984). Temu (1986) observed that use of *Crotalaria zanziberica* as green manure in the production of maize in Southern highlands of Tanzania was equivalent to 80-120 kg of fertilizer N/ha. Besides its reputation as green manure, marejea is claimed to be excellent forage crop, weed suppressor and soil ameliorant. On the basis of these attributes, marejea could be introduced to improve the productivity and efficiency of the farming systems in Kilimanjaro and similar regions. Despite of its popularity in Tanzania, literature referring directly to Crotalaria ochroleuca is lacking (Brown & Van de Wal 1988). The existing information on it relies heavily on the practical experience of the Catholic Missionaries based at Peramiho in Ruvuma Region.

This study was undertaken to assess:

- the effect on maize yield of Crotalaria ochroleuca incorporation alone or in combination with inorganic fertilizer in the highlands of Kilimanjaro region.
- the amount of biomass which can be availed as animal feed
- the possibility of fitting marejea-maize rotation in the existing bimodal rainfall regimes in the northern highlands of Kilimanjaro region.

MATERIALS AND METHODS

A split plot trial with four replications and nine treatment combinations was laid out on three locations in Kilimanjaro region: Lyamungu ARI (Humic Nitosol), Marangu Rawia (Luvic Phaozem) and Mandaka TTC (Humic Cambisol). Main plots received 0, 50, and 100 kg N/ha as urea corresponding to nil (N0), half (N1) and full dose (N2) of recommended N fertilizer for maize production in the area. The sunnhemp treatments in sub-plots were as follows: absence of sunnhemp (S0), sunnhemp bottoms ploughed under and tops cut for forage (S1), and sunnhemp plant ploughed under (S2). Sunnhemp seeds were broadcasted at a rate of 20 kg/ha at the beginning of short rains in November 1992. Three months later, just at flowering, the legume was cut at ground level, weighed, and then ploughed under the soil for subplot S2. For subplot S1, the tops of the legume were cut at 50 cm above ground level, weighed and then fed to cattle. The bottoms were also weighed and incorporated in the soil. At the stage of incorporation, marejea plants were dug from a wetted meter square plot, then roots were washed in a stream of water against a wiremesh. The plants were then cut and separated into roots, bottoms (above ground portion to 50 cm) and tops; dried in an oven to constant weight at 70°C, weighed and then ground ready for analysis.

Two weeks after marejea incorporation, the control plots (N0S0) were ploughed and Kilima maize variety was sown to all plots. The subplots measuring 5.4 m by 4.5 m consisted of six rows of maize, 75 cm apart and 60 cm between hills of 2 seeds. During maize planting, 30 kg P/ha was band applied to all plots as TSP. One third of N fertilizer was also applied to N receiving plots at planting in form of urea, and the remaining two thirds was top dressed at maize knee height after weeding. The maize was then left to grow until harvest.

At harvest, the maize plants were cut at ground level from the center four rows, and weighed to obtain biomass record. The cobs were weighed separately and the grain moisture was measured using a grain moisture meter.

Soil and Planting Analysis

Soil samples taken prior to field establishment (Table 1) and after harvesting were analyzed using standard methods: pH in a 1:2.5 soil: water extract, P by Bray method, exchangeable cations and CEC in NH_4Ac extract at pH 7.0, N by Kjeldahl method, and OC by Wakley and Black method. Plant samples were washed in teepol solution prior to digestion in nitric acid. Contents of N, P, and K in the digest were determined .

RESULTS AND DISCUSSION

Maize grain and stover yield

The results of maize and stover yield at Lyamungu, Marangu and Mandaka are contained in Table 2, 3 and 4, respectively.

At Lyamungu, sunnhemp treatment had a very highly significant effect on both grain and stover yields of maize. Both nitrogen, and nitrogen x sunnhemp interactions effect on grain yield were significant, indicating that the maize yield response to sunnhemp treatment depended on the level of nitrogen applied to the soil. Except at the high level of nitrogen (N100), incorporation of sunnhemp in the soil significantly increased maize grain yield over the non sunnhemp treatment. In all cases of N application, there was no advantage of ploughing-under the whole sunnhemp biomass (S2) over the bottoms (S1). This result

Table 1. Chemical and physical propeties of the surface soils (0-20 cm) of the trial sites.

Site	Lyamungu	Marangu	Mandaka
pH-H_2O	5.4	6.2	6.2
Organic C%	2.0	1.6	1.4
Nitrogen %	0.25	0.15	0.13
Bray P mg/kg	34	45	52
Clay %	28.0	20.6	22.2
Silt %	52	50	51
Fine sand %	13	23	20
Coarse sand %	25	18	21

implies that farmers of all income brackets can safely harvest the sunnhemp tops for animal feeding without sacrificing appreciable amounts of grain. There was also no yield advantage in applying high (N100) over moderate (N50) levels of N where sunnhemp manuring is practised. Ploughing-under of sunnhemp bottoms (N0S1) alone gave maize yields equivalent to the fertilizer application of 50 kg N/ha while the whole plant soil incorporation (N0S2) gave maize yields equivalent to 100 kg N/ha. In the absence of green manuring (S0), however, use of N fertilizer is inevitable if high yields are to be expected under Lyamungu and similar conditions. The most reasonable practice to adopt appears to be equivalent to N1S1 from which 6.9 t/ha grain and 8.2 t/ha stover was obtained in addition to sunnhemp tops to supplement livestock feed.

At Marangu the mean grain and stover yields were 3.2 and 6.8 t/ha, respectively, well below corresponding yield of 6.2 and 8.0 t/ha at Lyamungu. The low grain yield at this site is thought to be due to drought which set in at grain filling stage. This did not greatly affect the vegetative phase development as shown by high stover yield figures. The reason is further supported by high CV for grain relative to stover yields. At this site, sunnhemp treatments significantly ($p<0.001$) increased maize grain and stover ($p<0.05$) yields. Nitrogen had no significant influence on yields, partly due to drought and partly due to the fact that main plot N treatments were less precisely evaluated due to large main plot error (Cochran and Cox 1957, Kwamchai and Arturo 1984). In nil N-plots, sunnhemp practice S2 out-yielded S1 in both grain and stover and both S1 and S2 were superior to S0. This could be the result of better moisture retention by soils receiving greater mass of manure relative to non manured soils. It seems in dry years, when crop response to N is rather poor, whole plant soil incorporation of sunnhemp (S2) would be preferred over bottoms incorporation (S1), with no or only moderate levels of N.

At Mandaka, no differences could be observed between S1 and S2 treatments , but these treatment significantly out yielded the S0 treatment. There was hardly any effect of soil incorporation of sunnhemp where the highest amount of fertiliser N was applied.

Table 2. Effect of sunnhemp and nitrogen fertilizer combination on maize grain (t/ha) and stover yield (t/ha) at Lyamungu in 1992/93.

Sunnhemp practice	0 kg N/ha		50 kg N/ha		100 kg N/ha		Means	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
S0	4.3	5.5	5.9	7.5	6.6	8.1	5.6	7.0
S1	6.0	7.1	6.9	8.2	6.2	8.4	6.3	7.9
S2	6.6	8.0	6.9	9.9	7.0	9.1	6.8	9.0
Means	5.6	6.8	6.5	8.5	6.6	8.5	6.2	8.0

Grain yield $LSD_{5\%}$-S=0.50, Grain yield $LSD_{5\%}$-N=0.77
Stover yield $LSD_{5\%}$-S=0.9, Stover yield $LSD_{5\%}$-N=n.s.

Table 3. Effect of sunnhemp and nitrogen fertilizer combination on maize grain (t/ha) and stover yield (t/ha) at Marangu Rawia in 1992/93.

Sunnhemp practice	0 kg N/ha		50 kg N/ha		100 kg N/ha		Means	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
S0	2.0	4.0	2.7	6.8	2.1	4.8	2.3	5.2
S1	3.1	7.3	3.7	6.1	3.5	7.2	3.4	6.8
S2	4.0	9.3	3.7	9.2	3.8	6.4	3.8	8.3
Means	3.0	6.8	3.3	7.4	3.1	6.2	3.2	6.8

Grain yield LSD $_{5\%}$-S=0.70, Grain yield LSD $_{5\%}$-N=n.s.
Stover yield LSD $_{5\%}$-S=2.0, Stover yield LSD $_{5\%}$-N=n.s.

Table 4. Effect of sunnhemp and Nitrogen fertilizer combination on maize grain (t/ha) and stover yield (t/ha) at Mandaka in 1992/93.

Sunnhemp practice	0 kg N/ha		50 kg N/ha		100 kg N/ha		Means	
	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover
S0	2.1	4.9	1.2	4.6	3.7	6.9	2.3	5.4
S1	2.3	6.4	2.5	7.0	4.0	6.0	3.0	6.5
S2	2.8	7.2	2.5	5.4	3.9	5.7	3.1	6.1
Means	2.4	6.2	2.1	5.6	4.0	6.2	2.8	6.0

Grain yield LSD $_{5\%}$-S=0.20, Grain yield LSD $_{5\%}$-N=1.0
Stover yield LSD $_{5\%}$-S=0.70, Stover yield LSD $_{5\%}$-N=2.1

Nutrients concentration, nutrient yields and biomass of sunnhemp.

Nitrogen concentration was more than twice as high in the tops as compared to the bottom above ground parts (Table 5). Roots had a significantly higher nitrogen concentration than the bottom above ground parts. Most of K and P concentrated in the top part of the Crotalaria plant and generally decreased down to the roots.

Table 6 indicates that the amount of nutrient yields by sunnhemp cover crop varied over the three sites, with the mean value of 65.8 kg N/ha (44.9-81.3), 12.6 kg P/ha (9.6 - 17.0), and 50.6 kg K/ha (36.9 - 59.3).

In a system where only the bottoms and roots were ploughed under (S1), 3,2 ton dry matter of sunnhemp/ha was in average available as animal feed. This is sufficient to feed a 400 kg cow for one year and produce 3000 kg of milk/year (assuming a feeding rate of 9kg dry matter/cow/day (ILADCO 1991). Protein is in surplus as this feed contains 28.18%

Table 5. Nutrient contents % of different parts of sunnhemp grown on three sites.

	Lyamungu			Marangu Raw.			Mandaka			Mean		
	N	P	K	N	P	K	N	P	K	N	P	K
Tops	2.46	0.27	1.1	0.76	0.27	0.80	1.68	0.25	1.08	1.63	0.26	1.0
Bottoms	0.73	0.12	0.9	0.42	0.20	0.90	1.05	0.17	0.58	0.70	0.16	0.8
Roots	0.94	0.11	0.46	1.12	0.25	0.68	1.08	0.11	0.33	1.24	0.16	0.49

Table 6. Dry matter yield (t/ha) and nutrient yield (kg/ha) of sunnhemp for different sunnhemp management practices at three sites.

Site	Plant part	Biomass	N	P	K
Lyamungu	Tops	3.1	76.3	8.4	34.1
	Bottom + roots	2.5	20.4	2.0	18.1
	Tops, bottoms + roots	6.1	81.3	11.3	55.6
Marangu	Tops	4.2	31.9	11.1	33.6
	Bottom + roots	2.5	14.7	5.2	20.7
	Tops, bottoms + roots	7.0	44.9	17.0	59.3
Mandaka	Tops	2.3	38.6	5.8	24.8
	Bottom + roots	2.3	38.7	3.4	11.0
	Tops, bottoms + roots	5.0	71.2	9.6	36.9
Means	Tops	3.2	48.9	8.5	30.8
	Bottom + roots	2.4	21.6	3.8	16.6
	Tops, bottoms + roots	6.0	65.8	12.6	50.6

protein on D.M. basis (Sarwatt & Mkiwa 1987). Feed from Crotalaria can therefore upgrade the low quality fodder available in the region.

Besides animal feed, this practice still left behind 2.4 t of dry matter/ha for soil incorporation. This quantity of green manure supplies 21.6 kg N/ha and 16.6 kg K/ha. This is equivalent to 100 kg of sulphate of ammonia and 33 kg of muriate of potash. These amounts of fertilizer are probably underestimated as it was not possible to harvest all the root biomass from the soil. Together with other soil improvements possibly induced by sunnhemp manuring, these nutrients resulted in maize yields equivalent to 50 kg of N fertilizer. However, practically no change in soil properties were noticed after the first crop harvest.

SUMMARY AND CONCLUSION

On the strength of the preliminary data available, sunnhemp green manuring can successfully be grown in the short rains, in the highlands of Kilimanjaro region with bimodal rainfall pattern, as a soil conservation measure for improved productivity. Among the three alternatives of sunnhemp management tested, the whole plant incorporation resulted in maize yields equivalent to 100 kg of N fertilizer, and does not seem to offer significant maize yield advantage over the sunnhemp bottoms soil incorporation in normal rainfall situations. In dry areas, however, the whole plant incorporation out-yielded all the sole nitrogen application, probably due to better soil moisture retention. Under dry conditions this practice is to be preferred and works better with no or only moderate levels of fertilizer N.

The practice of cutting the tops and ploughing under the bottoms can provide up to 15 t/ha of forage to supplement livestock feed in short supply in the region, without sacrificing large amounts of grain harvest. The sunnhemp bottoms incorporation gave maize yields equivalent to 50 kg of fertilizer N/ha under normal rainfall situation. When sunnhemp bottoms are supplemented with 50 kg N/ha the peak maize yield corresponding to 100 kg N fertilizer was obtained, implying a possible N fertilizer cut by 50%.

Considering the shortage of animal feed and grain food in Kilimanjaro region, the practice of cutting the tops for livestock feeding and ploughing under the sunnhemp bottoms, supplemented with moderate levels of fertilizer N seems feasible. This practice can offer a most integrated and sustainable nutrient supply system, over the ongoing exploitive system of "cut and take all" from the maize fields. Moreover, the sunnhemp in this case is also serving as a forage crop so that the arguments against green manuring for the reason of loosing a season or lack of immediate return doesn't hold.

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Bioavailable Phosphorus status in some Benchmark soils of Morogoro district, Tanzania

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The objective of this study was to estimate available P in 11 Benchmark soils of Morogoro district using a recently developed procedure that includes both inorganic P (Pi) and organic P (Po) dynamics in soils. One set of soils was untreated while another set was enriched with carbon and nitrogen so as to raise microbial activities and create a biological sink for P similar to that found in the rhizosphere zone of plants. The treated soil samples were designated as bioactive. Samples were incubated for seven days at which time they were analysed for different P fractions. Bioactive soils had less inorganic P than untreated soils after incubation probably due to microbial immobilization. They also had higher values of inorganic plus microbial (Pi+m) than untreated ones. Labile Po increased by about three times in bioactive soils after incubation while no changes occurred in the untreated soils. This confirmed the role of microbial activity in increasing available P in soils especially those high in organic matter. Bioavailable P was obtained by adding Pi, Po and Pm. The r^2 between bioavailable P and relative yield was 0.64 and 0.61 for bioactive and untreated soils respectively. However the r^2 for the relationship between preincubated Olsen P (Pi) and relative yield was 0.69, indicating that the Olsen method gives a good estimate of phosphorous which is available to plants.

Key words: bioavailable phosphorous, microbial P, Olsen P, organic P, total P, yield correlation

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The importance of phosphorus as a plant nutrient is well known. Plant available P is the fraction of total P present in the soil in a pool of ions which can move to the roots and can be absorbed by plants during their period of growth (Barber 1984).

Many chemical soil testing methods have been developed to estimate available phosphorus in soils. Ussiri (1992) evaluated a number of these methods for some Benchmark soils of Morogoro district including methods developed by Truog (1930), Morgan (1941), Bray & Kurtz (1945), Olsen et al. (1954), Egner et al. (1960), Mehlich (1984) and Soltanpour & Schwab (1977). He concluded that the method of Olsen et al. (1954) estimated best the available P status in the Benchmark soils of Morogoro district. However, the Olsen method estimates available P from the inorganic P (Pi) pool of the soil only. According to

Thien & Myers (1992), soil tests that measure only Pi can underestimate potential available phosphorus (AP) because they exclude P from other pools such as the organic and microbial pools. They, therefore, developed a bioavailable P index which incorporates P from the inorganic, organic and microbial pools.

The objective of the present study was to determine bioavailable phosphorus in the Benchmark soils of Morogoro district used by Ussiri (1992) and assess its usefulness as an index of available P in the soils.

MATERIALS AND METHODS

Soil was collected from the plough layer (0 - 15 cm depth) at eleven (11) locations selected earlier as representative Benchmark soils of Morogoro district (Ussiri 1992) (Table 1). The soil samples were air dried, sieved through a 2 mm screen and stored at room temperature. Soil pH was determined in 1:2.5 soil/water mixture by using a glass electrode. Organic matter content was determined by following the Walkley and Black procedure as described by Allison (1965). Readily extractable or labile Pi in 4.0 grams of soil was determined by following the Watanabe & Olsen (1965) procedure modified to include centrifugation steps prior to filtration and spectrophotometric analysis.

Four grams of each soil were weighed into each of four test tubes. Soil samples in two tubes received 1.5 ml of a 10:1 C + N solution (0.44 M dextrose and 0.24 M NH_4Cl) and were designated as bioactive (+) soils while the other two tubes received 1.5 ml of distilled water and were designated as untreated (-) soils. Following this treatment the soils were incubated in a water bath at 35° C for seven (7) days. Details of the incubation conditions and extraction scheme are

Table 1. Soil names of the Benchmark sites by FAO-UNESCO (1989) and soil taxonomy systems of classification

Location	FAO-UNESCO classification	US Taxonomy classification
1. Wami Dakawa Cholima	Gleyic Cambiso	VerticTropaquept
2. Wami Dakawa Rice Farm	Calcic Vertisol	Typic Pellustert
3. Mvomero primary school	Eutric Fluvisol	Fluvaquentic Haplaquoll
4. Wami vijana	Eutric Fluvisol	Vertic Fluvaquent
5. Pangawe	Vertic Luvisol	Vertic Ochraqualf
6. Mlali	Haplic Acrisol	Typic Kanhaplustult
7. Kingolwira	Rhodic Ferralsol	Rhodic haplustox
8. Mkundi	Dystric Regosol	Tropaquent
9. Getini (SUA 1)	Haplic Acrisol	Kanhaplic Haplustult
10. Magadu (SUA 2)	Haplic Acrisol	Kanhaplic Haplustult
11. Melela	Eutric Vertisol	Paleustollic Pellustert

reported by Thien & Myers (1992).

One bioactive and one untreated sample of each soil were analysed for Pi and Pt (set A). For Pi determination, the Watanabe & Olsen (1965) method was employed. In Pt determination the $K_2S_2O_8$ (dipotassium peroxodisulphite) digestion procedure of Bowman (1989) was adapted to determine the Po in the $NaHCO_3$ extract. The purpose of digestion was to convert organic P so that subsequent determination of P in these samples gave total P (P_t).

Determination of microbial P was achieved by lysing the remaining set of incubated samples (set B) by fumigation. The samples were treated with 2 ml of chloroform, capped for 36 hours at room temperature and then uncapped for 24 hours to allow chloroform to evaporate as recommended by McLaughlin et al. (1986). Phosphorus in the soil samples was then extracted following the Olsen et al. (1954) method. The P value obtained represented Pi plus Pm released by the lysing step and was designated as Pi + m. A recovery factor of 0.4 was employed because the lysing procedure followed recovers only 40% of the microbial P (McLaughlin et al. 1986).

RESULTS AND DISCUSSION

The physical-chemical properties of the eleven soils used in this study have been reported by Ussiri (1992) but a few of these are shown in Table 2. Soil pH ranged from 4.8 to 7.9 and organic matter content from 7.7 to 38.8 g/kg.

Table 2. Soil properties prior to incubation treatments and relative yield data

Site name	pH	OM gkg^{-1}	P_T^{pre} $mgkg^{-1}$	Pi^{pre} $mgkg^{-1}$	Po^{pre}	Relative yield*
1. Wami Dakawa cholima	5.9	11.2	23.0	14.5	8.5	92.1
2. Wami Dakawa rice farm	7.9	7.7	23.0	13.0	10.0	ND
3. Mvomero primary school	7.0	26.8	45.0	36.0	9.0	104.1
4. Wami vijana	6.0	19.1	32.0	28.0	4.0	102.6
5. Pangawe	5.8	33.8	18.0	9.5	8.5	37.0
6. Mlali	5.8	25.1	14.0	9.5	4.5	63.5
7. Kingolwira	5.5	36.5	18.0	9.5	8.5	36.0
8. Mkundi	5.8	16.5	18.0	9.5	8.5	47.1
9. Getini (SUA 1)	4.8	10.8	14.0	9.5	4.5	32.7
10. Magadu (SUA 2)	5.0	23.5	18.0	12.0	4.0	65.4
11. Melela	7.7	38.8	23.0	18.5	4.5	71.1

Pi^{pre} = preincubation inorganic P
Po^{pre} = preincubation organic P
P_T^{pre} = preincubation total P
ND = not determined
* *= relatlive yield data were obtained fron Ussiri (1992)*

Preincubated Pi and Po ranged from 9.5 to 36 mg P kg^{-1} and 4.0 to 10.0 mg P kg^{-1}, respectively (Table 2). Thus labile organic P was less than labile inorganic P in our experimental soils, unlike soils used by Thien & Myers (1992) majority of which had higher contents of labile organic P than inorganic P.

Inorganic, organic and microbial phosphorus

As noted earlier, one set of the experimental soils was untreated while another was enriched with C and N to raise microbial activities and create a biological sink for P. The untreated soils represented non rhizosphere soil conditions. The C and N added to the bioactive soils simulated the energy rich conditions found in the rhizosphere zones of plants. Thus, the results on the dynamics of P in these enriched soils will enable the evaluation of the soils' potential to supply P to actively growing roots.

Bioactive soils always had less Pi than untreated soils after incubation (Table 3a). Values ranged from 4.0 to 24 mg P kg^{-1} and from 6.3 to 32.3 mg P kg^{-1} for bioactive and untreated soils, respectively. Thien & Myers (1992) obtained similar results which they attributed to microbial immobilization in bioactive soils due to enhanced microbial activities.

Labile Po after incubation ranged from 13.6 to 25.5 mg P kg^{-1}. These values were greater than Po levels prior to incubation which ranged only from 4.0 to 10.0 mg P kg^{-1} (Table 3). Comparing the pre- and post- incubation Po levels (Tables 2 & 3) shows that incubation raised Po in the bioactive soils by approximately 3 times while it essentially had no effect in the untreated soils.

Postincubation Po correlated closer to preincubation Po in the untreated soils ($r^2 = 0.56$) than for the bioactive soils ($r^2 = 0.23$)

Table 3a. Assayed and calculated parameters in soils incubated with (+) and without (-) supplemental C and N

Site name	Pi^+	Pi^-	Pt^+	Pt^-	$Pi+m^+$	$Pi+m^-$	Po^+	Po^-	Pm^+	Pm^-
Wami Dakawa Cholima	4.8	9.5	24.0	19.0	21.5	15.5	19.3	9.54	1.9	20.0
Wami Dakawa Rice Farm	4.0	7.0	24.0	19.0	13.5	11.5	20.0	12.0	23.1	11.3
Mvumero Primary School	24.0	32.2	49.5	40.0	34.5	26.5	25.5	7.8	26.3	14.4
Wami Vijana	14.8	20.0	30.5	24.0	26.5	22.5	15.8	4.02	9.4	5.0
Pangawe	5.5	8.8	24.0	19.0	12.8	10.5	18.5	10.3	18.1	4.4
Mlali	5.5	8.3	19.0	14.5	9.3	5.6	13.5	6.3	9.4	6.9
Kingolwira	4.0	6.3	19.0	14.5	10.5	8.5	15.0	8.3	16.3	4.4
Mkundi	4.0	6.3	21.5	14.5	9.3	7.5	17.5	8.3	13.1	3.1
Getini	5.5	7.5	24.0	14.5	12.0	8.5	18.5	7.5	16.3	2.5
Magadu	4.0	7.0	19.0	14.5	11.3	8.5	15.0	8.5	18.1	3.8
Melela	8.3	14.3	28.5	19.0	20.0	16.0	20.3	4.8	29.4	4.4
Mean	7.7	11.6	25.7	19.4	16.5	12.8	18.1	7.8	21.9	7.3

Table 3b. Assayed and calculated parameters in soils incubated with (+) and without (-) supplemental C and N.

Name of the station	Pimmob+	Pimmob-	Pmin+	Pmin-	Bioavailable Po+	Po-	Bioavailable P+	P-
Wami Dakawa Cholima	9.8	5.0	61.1	29.5	51.4	24.8	65.9	39.0
Wami Dakawa Rice Farm	9.0	6.0	43.1	23.3	30.4	17.3	47.1	30.3
Mvomero Primary School	12.0	3.8	51.8	22.1	44.8	18.4	75.8	54.4
Wami Vi jana	13.3	8.0	45.1	9.0	37.4	1.0	59.9	29.0
Pangawe	4.0	0.8	36.8	14.6	28.9	13.9	42.1	23.4
Mlali	4.0	1.3	22.7	13.1	16.9	11.9	28.4	21.4
Kingolwira	5.5	3.3	31.3	12.6	23.0	9.4	35.3	18.9
Mkundi	5.5	3.3	30.6	11.4	21.1	8.1	34.6	17.6
Getini	4.0	1.8	34.8	9.5	27.0	8.0	40.3	17.5
Magadu	8.0	5.0	33.1	11.3	22.4	6.3	37.1	19.3
Melela	10.3	4.3	49.6	9.1	38.6	4.9	57.9	23.4
Mean	7.8	3.9	40.0	15.0	31.1	11.3	47.7	26.7

(Table 4). Thien & Myers (1992) observed a similar effect and attributed it to P containing metabolites that tend to accumulate in zones with increased microbial activity such as those found in bioactive soils. This is supported by a lack of correlation between microbial P with either preincubation Pi or Po (Table 4).

Immobilized inorganic phosphorus

The difference in Pi before and after incubation gives an estimate of immobilized P (P immob). This P pool ranged from 4.0 to 13.3 mg P kg^{-1} in bioactive soils and from 0.8 to 8.0 mg P kg^{-1} in the untreated soils (Table 3), indicating that less immobilization occurred in the untreated soils. Percentagewise, the proportion of Pi^{pre} immobilized in the bioactive soils ranged from 33% to 69% with an average of 53%. In the untreated soils it ranged from 8 to 46% with an average of 27%. Thien & Myers (1992) observed a similar trend but their proportions of immobilized P were higher possibly because in many of their experimental soils organic P exceeded the inorganic P fraction.

The amount of P immobilized in bioactive soils was more correlated (r^2 = 0.72) to preincubation Pi than in untreated soils (r^2 = 0.25) (Table 4). Immobilization occurs through transfer of available P from the Pi pool to either the Pm or Po pools and tends to temporarily decrease the Pi that can be taken up by plants until these pools are mineralized. Thus, the relatively high extent of Pi immobilization observed in the bioactive soils indicates that labile Po and Pm mineralization is important for maintaining

Table 4. Regression coefficients (y = a + bx) amd r^2 values for preincubation levels of Pi and Po and postincubation parameters determined int his experiment

Property	Pi^{pre}			Po^{pre}		
	a	b	r^2	a	b	r^2
Pi^+	-2.80	0.679	0.92**	7.40	0.038	0.0002
Pi^-	-2.04	0.882	0.95**	11.02	0.077	0.0005
Pt^+	11.75	0.907	0.85**	20.98	0.702	0.04
Pt^-	7.20	0.786	0.62**	13.46	0.864	0.08
Pi^+ + m	1.67	0.724	0.93**	14.68	0.262	0.005
Pi^- + m	2.25	0.889	0.92**	11.14	0.248	0.008
po^+	14.56	0.228	0.37*	13.57	0.665	0.23
Po^-	9.50	-0.103	0.16	3.03	0.720	0.56**
Pm^+	13.82	0.527	0.25	18.35	0.529	0.02
Pm^-	3.57	0.240	0.16	-0.62	1.166	0.26
$Pimmob^+$	2.81	0.321	0.72**	7.97	-0.032	0.01
$Pimmob^-$	1.99	0.120	0.25	4.27	-0.063	0.01
$Pmin^+$	28.40	0.754	0.36	31.90	1.197	0.07
$Pmin^-$	12.81	0.145	0.04	1.81	1.954	0.48
Bioavailable P^+	25.57	1.433	0.71**	39.33	1.230	0.04
Bioavailable P^-	11.04	1.018	0.64**	13.43	1.964	0.18
Bioavailable Po^+	18.81	0.796	0.43*	24.16	1.020	0.05
Bioavailable Po^-	10.90	0.023	0.01	-2.39	2.014	0.50*

*, ** = *significant at the 0.05, 0.01 probability levels respectively*
i = *inorganic*
t = *total*
m = *microbial*
o = *organic*
immob = *immobilzed*
min = *mineralized*
pre = *preincubation*

adequate available P in the rhizosphere, especially in organic matter rich soils.

Potentially mineralizable phosphorus

Mineralizable phosphorus (Pmin) is obtained by summation of the organic P (Po) and microbial P (Pm) pools. Values for this P pool are also shown in Table 3. Predictably, bioactive soils had more Pmin than untreated soils. The values ranged from 22.9 to 61.1 mg P kg^{-1} in bioactive soils compared to 9.0 to 29.5 mg kg^{-1} in untreated soils.

Low and non-significant correlation was observed between the quantity of the Pmin pool and both preincubation Pi and Po pools (Table 4), suggesting that these preincubation P pools are poor indicators of the Pmin pool. These results are in agreement with those of Thien & Myers (1992), who attributed the results to the possibility that some non extractable pools are accessed by microbes and converted to Po and Pm.

Total bioavailable Phosphorus

Total bioavailable P was obtained by combining the Pi, Po and Pm pools (Table 3). The magnitude of the bioavailable P indicates that if only Pi is relied upon to determine the potential of a soil to supply P to plants, the available P potential of that soil would be greatly underestimated. The present results provide further evidence in support of the proposal by Thien & Myers (1992) that the bioavailable P index provides a more realistic assessment of the P-supplying power of a soil.

Preincubation Pi correlated well with bioavailable P in both bioactive and untreated soils (r^2 = 0.71 and 0.64, respectively) (Table 4). This indicated that the bioavailable P represents a significant portion of the preincubation Pi pool. No significant correlation between preincubation Po and bioavailable P in bioactive or untreated soils was observed (Table 4), indicating that this pool made an insignificant contribution to bioavailable P.

Bioavailable Organic Phosphorus

The portion of bioavailable P derived from organic pools (bioavailable Po) is found by reducing the potentially mineralizable Po (Po + Pm) by the amount of immobilized Pi.

Bioavailable Po in bioactive soils was higher than either preincubation Po or Pi (Table 3). The values ranged from 16.9 to 51.4 mg P kg^{-1} in constrast to the preincubation values which ranged from 4.0 to 10.0 mg P kg^{-1} for $P_o$pre and 9.5 to 36.0 mg P kg^{-1} for Pi^{pre}. This indicated that where there is no fertilization, this pool may play a predominant role in controlling plant available P. It also implies that continuing the use of preincubation soil tests for determination of potentially available soil P status may lead to underestimation of the same hence leading into unnecessary excessive application of P fertilizer in soils.

Relationships between bioavailable P and its component P indices with relative yield

Thien & Myers (1992) did not relate the bioavailable P index they developed with crop growth. In order to assess the usefulness of this index in assessing available P to plants, we correlated the indices with crop growth. This was done using relative maize yield data reported by Ussiri (1992) from glasshouse experiments using soil samples from the same sites. Preincubation Pi values correlated well with relative yield (r^2 = 0.69) (Table 5). This was in agreement with the results of Ussiri (1992) who observed an equally good association between the two parameters. This further confirmed the usefulness of preincubation Pi in assessing available P for the experimental soils reported by Ussiri (1992).

Postincubation Pi values were also correlated with the relative yield. The r^2 values were 0.58 and 0.50 for untreated and bioactive soils, respectively (Table 5). However, the association was not as strong as observed for preincubation Pi values. The main reason for this could be due to microbial immobilization of Pi which was quite substantial (Table 3). No relationship was found between relative yield and either Po^+ or Po^-.

The microbial P was slightly correlated to the relative yield (r^2 = 0.48) for bioactive soils and (r^2 = 0.42) for untreated soils (Table 5). This indicates that this P pool does contribute to some extent to the soil P which becomes available to plants.

Bioavailable Po in bioactive soils was

Table 5. Relationship between bioavailable P and its component fractions with relative yield

Property	a	b	r^2
Pi^{pre}	26.99	2.454	0.69**
Pi^+	41.22	2.988	0.50**
Pi^-	35.33	2.489	0.58*
Po^+	10.39	3.065	0.15
Po^-	106.79	-5.546	0.16
Pm^+	22.89	1.940	0.48*
Pm^-	43.82	3.108	0.42*
BPO^+	11.84	1.713	0.51*
BPO^-	56.30	0.835	0.05
BP^+	-0.44	1.376	0.64**
BP^-	17.61	1.804	0.61**

*, **, = *Significance at the 0.05, 0.01 probability levels, respectively*
pre = *preincubation*
I = *inorganic P*
o = *organic P*
m = *microbial P*
BPO = *bioavailable organic P*
BP = *total bioavailable P*

slightly correlated to the relative yield (r^2 = 0.51), but no significant association was observed on the untreated soils. The good correlation observed in bioactive soils underscored the importance of including this pool as a component of the overall bioavailable P index, especially in organic matter rich soils.

The total bioavailable P correlated well to the relative yield in both bioactive (r^2 = 0.64) and untreated soils (r^2 = 0.61) (Table 5). This strong association between the two parameters indicated that the bioavailable P index reflects well the soil P fraction which is taken up by plants.

The r^2 values observed were, however, lower than that observed between relative yield and Pipre (Table 5), indicating that Pipre (which is the Olsen extractable P) was still a better predictor of available P than bioavailable P. This could be attributed to the fact that the organic P content in all the experimental soils was by far less than inorganic P (Table 1). Therefore, even though contribution from the Po pool increased during incubation as a result of microbial activity, the overall contribution from organic P to available P was less significant. Consequently, its inclusion in the bioavailable P index may not have made much difference in this particular case.

CONCLUSION

A procedure described by Thien & Myers (1992) was used to generate indices for estimating bioavailable P for some Benchmark soils of Morogoro district. Of the indices generated, postincubation Pi and microbial P, contributed to the available soil P as reflected by significant r^2 values ranging from 0.42 to 0.58.

The bioavailable P data obtained correlated well with relative yield with r^2 of 0.64 in bioactive soils and 0.61 in untreated soils. However, the r^2 between preincubated Olsen P and relative yield was higher, being 0.69.

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Effects of Alley Cropping with Leucaena leucocephala and incorporation of its prunings on the phosphorus status of an Andosol from Uyole, Mbeya, Tanzania

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The objective of the study was to determine the effects of alley cropping with Leucaena leucocephala and incorporation of its prunings on the phosphorus status of an Andosol from Uyole, Mbeya. Soil samples were collected from an alley cropping experiment at MARTI Uyole, Mbeya, which has been running for over ten years. The samples were analysed for organic carbon, total phosphorus, organic P and Olsen extractable P. The results of soil analysis indicated plots receiving Leucaena prunings in combination with nitrogen fertilizer over a period of 11 years had a higher organic matter content than the control plots. This also caused a higher level of organic phosphorus and total P. The Olsen bicarbonate extractable P was also higher in plots receiving prunings, though to a small extent in proportion to observed increases in organic P. The small increase in Olsen extractable P was thought to be the result of underestimating the potentially available P because the procedure used estimates inorganic P in the extracts only. A bioavailable P index which includes organic and microbial P, in addition to inorganic P will be used to reassess the effects of the treatments on extractable P. Nevertheless, the results show that incorporation of organic residues from alley cropped trees partly influences soil fertility status through its positive effects on P balance in the soil.

Key words: alley cropping, andosols, Leacuena lecophephala, Olsen P, organic phosphorus, prunings

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Various crop production technologies have been tested in the humid tropics to replace the traditional bush fallow system to increase food production. One of the alternate promising methods is the alley cropping system described by Kang et al. (1981). This system involves the growing of food crops in alleys formed by hedgerows of trees or shrubs that are periodically pruned during the crop growing season to minimize the adverse effects of shading and to reduce competition with the food crops.

In the Southern Highlands of Tanzania research on alley cropping was initated in 1981 at Uyole, Mbeya to investigate the effect of alley cropping on maintenance of soil fertility and its effect on crop production (Kamasho 1993). The results of the study showed that application of Leucaena prunings had a positive effect on the organic carbon and total N contents of the soil (Kamasho 1993). The amounts of exchangeable bases (K, Na, Ca, Mg) and cation exchange capacity (CEC) were also higher in the plots under leucaena vegetation than on check plots. Incorporation of the leucaena prunings therefore resulted in a general increase in soil fertility compared to the control plot and this was reflected in better crop performance. The higher level of organic matter with the incorporation of Leucaena prunings implies also an increase in the organic fraction of nutrients such as phosphorus. It is therefore important to quantify this contribution to soil P dynamics.

The present study is, therefore, a continuation of the agroforestry research at Uyole and its main objective was to assess the effects of incorporating leucaena prunings on alleys planted with maize on phosphorus status in the experimental soil.

MATERIALS AND METHODS

This study was carried out using soil samples taken from an alley cropping experiment started in April 1981. The experiment is situated at MARTI, Uyole in Mbeya on a very fine sandy loam soil classified as Xeric Eutrandept in the USDA Soil Taxonomy System, and as Haplic Phaoezems in the FAO system of classification (Romblow- Pearse & Kamasho 1982).

In this experiment, *Leucaena* variety K-28 seedlings were planted at a spacing of 0.5 m within rows and 4 m between rows. Six leucaena rows were established in this way giving four alleys each of which was 79 m long. The alleys remained under natural grass fallow until November 1983 when *Leucaena* establishment was complete.

A trial was then established on the alleys in the 1983/84 season to evaluate the effects of incorporating leucaena prunings with and without added nitrogen on soil productivity, using maize as the test crop. The trial was laid out following a split plot design with three (3) replications. The treatments were as follows:

Mulch treatments (main plots):
1. Leucaena alleys. Mulch removed
2. Leucaena alleys.
   2.5 tons fresh mulch/ha
3. No leucaena alleys.
   5 tonn fresh mulch/ha

Three N rates were applied in the subplots as Calcium ammonium nitrate (CAN) to supply N to the maize crop:
a. 0 kg of N/ha
b. 30 kg of N/ha
c. 60 kg of N/ha

20 kg of P/ha was applied annually to the maize crop. The *leucaena* plants were pruned three times per growing season for the 11 years of studies. Maize (Hybrid variety H6302) was seeded in the alleys at a spacing of 60 x 75 cm. Three seeds were planted which upon germination were thinned to two plants per hill. Harvesting was done at crop maturity. After the maize cobs were removed the straw was removed from the plots and burnt.

Soil sampling procedure

Soil samples (0 - 20 cm) were taken in November, 1993 from each plot of the alley trial described above. Samples were taken randomly in each plot, mixed to get a homogeneous composite sample, air dried and ground to pass throgh a 2 mm sieve for laboratory analysis.

Soil analysis

Soil pH was determined in H_2O (1:2.5:H_2O) using a glass electrode pH meter. Organic carbon was analysed following the Walkley and Black Method (Allison 1965). Total phosphorus was determined by digesting samples with 60% $HClO_4$ as described by Olsen & Dean (1965). The P content in the digest was then measured using the ascorbic acid-molybdate blue method as described by Murphy & Riley (1962). Acid concentration in P standards was brought to the same level as in the digested samples in order to maintain a similar pH in both standards and samples.

Organic P was determined indirectly by the ignition method described by Saunders & Williams (1955) and modified by Walker & Adams (1958). A temperature of 550°C was used in the muffle furnace for ashing and oxidising soil organic matter before acid extraction of total orthophosphate using H_2SO_4. A non ignited sample was concurrently extracted with the same acid to determine inorganic P. Phosphorus in extracts was measured following the ascorbic acid molybdate blue method as described by Watanabe & Olsen (1965). The organic P content of the soil samples were then calculated by substracting P in the unignited samples from P in the ignited samples.

Extractable P was determined following the Olsen method (Olsen et al., 1954).

Data Analysis

The collected data were analysed statistically following standard analysis of variance procedures (Steel & Torrie 1980). The New Duncan Multiple Range Test was used to compare differences between means.

Table 1. Effect of added Leucaena prunings at different rates on contents of organic carbon and different P fractions

Treatments	Mean values within different treatments				
Leucaena ton/ha	% OC	Organic P mg/kg	% Total P	Bray P mg/kg	Olsen P mg/kg
0	0.84c	219b	0.20c	11.0b	8.6b
2.5	1.23b	219b	0.24b	15.2a	8.8b
5.0	1.40a	274a	0.30a	15.8a	10.8a

a, b, c = Means within the same column followed by the same letter are not significantly different at P < 0.05 according to the Duncan's New Multiple Range Test

RESULTS AND DISCUSSION

The treatment effects on soil organic carbon and different soil P fractions are shown in Tables 1 and 2 for the main effects and Table 3 for the simple effects. Each parameter is discussed individually below.

Organic carbon

Application of 2.5 t/ha and 5 t/ha of *leucaena* as green manure had a significant effect on the organic carbon content of the soil (Table 1). This higher level of soil organic carbon in plots receiveing prunings resulted from the decomposition of the leucaena prunings. Similar observations were reported by Lal (1989) in Nigeria, and Marandu and Shirma (1989) at Mlingano Tanga. They showed that application of leucaena prunings had a positive effect of the organic carbon content in their respective experimental soils.

The soil organic carbon was also higher in plots receiving nitrogen fertiliser compared to control plots Table 2. Furthermore, application of Leucaena prunings in combination with added N had a positive effect on the soil organic carbon content (Table 3). Since residues were removed from the plots, this effect of N fertilizer probably resulted from the effect of added N on the root biomass produced. This additional carbon together with that introduced with the prunings accounted for the overall increases in organic carbon observed.

Organic P

The level of organic P was higher in plots where *leucaena* prunings where applied compared to the control plots. This result is attributed to the effects of the prunings on the organic carbon and is confirmed by the good correlation observed between organic C and organic P (Table 4).

Addition of nitrogen also resulted in an effect in organic P at each rate of N application (Table 2). Further, the combination of *leucaena* prunings with added N had a complimentary effect on the organic P content (Table 3). Thus, at each level of added prunings, organic P increased with increasing rate of N application.

Table 2. Effect of nitrogen application on levels of organic carbon and different P fractions

Treatments	Mean values within the same treatments				
Nitrogen kg/ha	% OC	Organic P mg/kg	% Total P	Bray P mg/kg	Olsen P mg/kg
0	1.08c	228c	0.19c	14.0a	10.8a
30	1.16b	237b	0.25b	14.1a	8.9b
60	1.24c	248a	0.30a	13.8a	8.4c

a, b, c, d, e, f = means within the same column followed by the same letter are not significantly different at $P < 0.05$ according to the Duncan's New Multile Range Test

Table 3. Effects of incorporating Leucaena prunings at different rates with and without nitrogen on contents of organic carbon and different P fractions

Treatments		Mean values within the same treatments				
Leucaena tons/ha	Nitrogen kg/hg	% OC	Organic P kg/ha	Total P in %	Bray P mg/kg	OlsenP mg/kg
0	0	0.72e	212e	0.12f	11.2c	10.7b
0	30	0.89d	223cd	0.22de	11.5c	9.0
0	60	0.92d	223cd	0.27bc	10.3d	6.0e
2.5	0	1.15c	217de	0.19e	16.4a	9.7a
2.5	30	1.19c	208e	0.24cd	14.5b	7.7d
2.5	60	1.34b	233c	0.30ab	14.7b	9.0cd
5.0	0	1.36ab	255b	0.27b	14.5b	12.0a
5.0	30	1.40ab	280a	0.29b	11.5a	10.0bc
5.0	60	1.45a	288a	0.33a	10.3a	10.3b

a, b, c, d= *means within the same column followed by the same letter are not significantly different at P < 0.05 according to the Duncan's New Multiple Range Test*

Table 4. Relationship between organic carbon and different P fractions.

Parameters	r - value
Organic carbon and total P	0.804***
Organic carbon and organic P	0.738*
Total P and organic P	0.745*
Organic P and Olsen P	0.313

* *Significant at P < 0.05*
*** *significant at P < 0.001*

Total P

The effect of incorporating leucaena prunings on the alleys with and without ferilizer N on total P followed the same trend as observed for organic P (Tables 1, 2 and 3). This was expected since total P is the sum of organic and inorganic P, so that changes in any of these P fractions results in a corresponding effect on the total P value. This results is also reflected in a significant correlation between total P and organic P (Table 4).

Available phosphorus

The available P content as estimated by the Olsen method reflected the effects of 20 kg P/ha applied annually to the maize as well as those of the added leucaena prunings. It also represents the available P content which had not been utilised by the previous crops of maize and leucaena shrubs growing on rows next to the alleys. Because added P was applied at a uniform rate of 20 kg P/ha to all plots, any difference between treatment means must be attributed to the effects of the incorporated leucaena prunings. Available P was higher in plots which had received prunings than in control plots (Table 1). The increase was significant at 5 t/ha and implied that the leucaena prunings decomposed and mineralized to release inorganic P. Marandu and Shirima (1989) observed similar results from an experiment conducted at Mlingano, Tanga.

The correlation between organic P and Olsen extractable P was positive but not significant (Table 4) suggesting that the observed increases in organic P did not result in corresponding increases in available P. This could be explained in part by the fact that some of the mineralized P was taken up by the maize plants and leucaena shrubs prior to the sampling and analysis of soil samples. However, it could also be attributed to the fact that the procedure for estimating P in the Olsen extracts estimates inorganic P only. It therefore underestimates the potential available P by excluding P from the organic and microbial P pools in the extracts. The contribution of organic P to potentially available P is expected to be significant in this case because of the effect of the incorporated prunings. The recently developed bioavailable P index (Thien & Myers 1992) might give a better available P picture since it incorporates P from the organic and microbial pools, in addition to the inorganic P. Analyses for this parameter are in progress and will be reported in due course.

Application of N significantly reduced Olsen extractable P with increasing rate of application (Table 2). This could be attributed to the fact that higher rates of N application resulted in greater maize growth (Kamasho 1993) and presumably greater nutrients (including P) uptake compared to lower rates of application where growth was limited. This disproportionate cumulative mining of P led to the current situation where higher levels of available P are found where no or lower rates of N were applied.

CONCLUSIONS

Addition of Leucaena pruings over a period of 11 years had a positive effect on the organic matter content compared to the control. This effect is organic matter content also had a positive effet on the organic phosphorus and hence total P. The Olsen bicarbonate extractable P was also influenced, though to a small extent in proportion to observed increases in organic P.

The small effect on Olsen extractable P is thought to be the result of underestimation of potentially available P because the procedure used estimates inorganic P in the extracts only. The bioavailable P index which includes organic and microbial P in addition to inorganic P will be used to reassess the effects of the treatments on extractable P. Nevertheless, the results show that incorporation of organic residues from alley cropped trees partly influences soil fertility status through its positive effects on P balance in the soil.

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Research priorities in soil management for sustainable land use

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Principal issues in soil management are: (i) soil degradation, (ii) lack of resources for transforming subsistence farming into commercial agriculture, and (iii) reconciling agricultural sustainability with high productivity and environmental quality. An important aspect of agricultural sustainability is establishing an increasing trend in per capita productivity while enhancing the resource base and improving environmental quality. A relevant strategy is restoration of the fertility of degraded soils especially that of acid infertile soils. Severity and type of soil degradation should be assessed in terms of productivity for different landuse systems and the management input. The onsite impact of erosion should be quantified in terms of productivity, economic loss, and change in soil properties. Long-term field experiments are needed to assess the management effects on nutrients and organic matter dynamics, Al concentration and base saturation. Critical limits of soil properties need to be established in relation to productivity. Reasons for the lack of low level of technology adoption should be identified, and farmer should be made part of the planning process in a multidisciplinary team approach. Research must be original, innovative, problemsolving and productoriented.

Key words: Soil degradation, soil management, soil quality, soil resilience, sustainability

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Food production in sub-Saharan Africa (SSA) has lagged behind the demand since 1970s. The deficit is aggravated and perpetuated by combination of social, cultural, ethnic and bio-physical factors. Important among biophysical factors are fragile and limited soil and water resources and harsh climatic conditions. Despite the poor socio-economic and political conditions, potential of soil and water resources is also being questioned. Are soil and water resources of SSA adequate to provide the basic necessities of rapidly growing population? How can the soil and water resources be managed so that their productivity is enhanced? Judicious management is crucial to enhancing and sustaining the desired level of productivity.

Soil management implies manipulating water and nutrient reserves within the rooting depth to enhance agronomic productivity, accentuate aesthetic values and minimize risks of environmental degradation. Soil management for sustainable use means (i) enhancement of soil structure through soil surface management for minimizing risks of degradation of soil structure, (ii) soil water conservation and management including drainage, irrigation, and runoff management, (iii) soil temperature management, (iv) nutrient capital enhancement and management and alleviation of nutrient deficiency and toxicity constraints, and (v) enhancement and management of soil organic matter content and activity and species diversity of soil fauna including biomass carbon. Fig. 1 depicts those aspects of soil management which have direct impact on agronomic productivity. In addition, however, there are ecological and environmental regulatory aspects of soil management. Important among these are soil capacity to regulate quality of water resources and buffer gaseous composition of the atmosphere. There are also cultural and aesthetic aspects of soil that require special management to meet these needs. Sustainable use of soil and water resources implies long-term use for meeting present and future needs and maintaining environmental regulatory functions. In the context of SSA, agricultural sustainability means an increasing or non-negative trend in per capita productivity. Furthermore, productivity is essential in terms of the efficient use of the most limiting or the non-renewable resource. The latter may be: (i) use of plant available nutrient reserves in soil with nutrient deficiency for resource-poor farmers, (ii) use and quality of water resources in semi-arid and arid regions, (iii) use or depletion of soil organic matter content, (iv) reduction of soil`s rooting depth in a system that enhances risks of soil erosion, and (v) flux of radiatively-active or greenhouse gases (e.g. CO_2, CH_2, N_2O,CFCs etc) in relation to agricultural activities. In terms of productivity and environmental quality, sustainable systems are those that maintain an increasing or a non negative trend either with science based inputs or with alternate landuse systems involving highskill management.

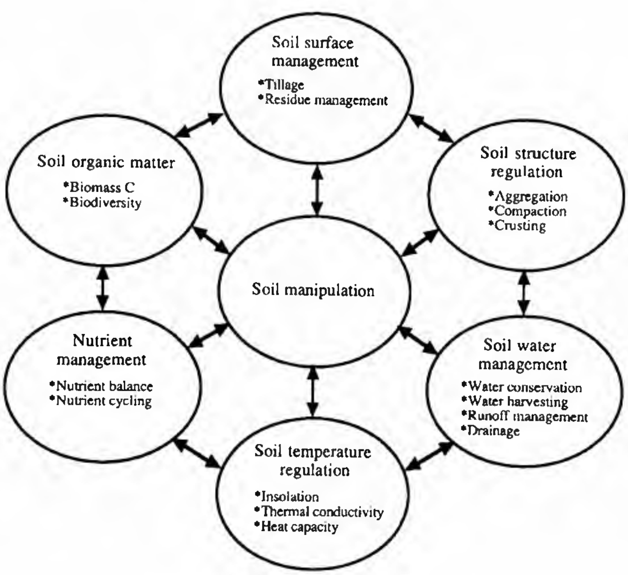

Figure 1. Manipulating plant available water and nutrient reserves within the root sone to optimize productivity and regulate environment.

Use of marginal soils, in harsh environment and ecologically-sensitive regions, is often unsustainable with no input widely practiced in SSA (Fig. 2). Sustainable use of such soils means either change of land use or adoption of science-based agricultural systems based on judicious use of off-farm inputs to replace the nutrients harvested or lost through degradative processes.

Sustainability of agricultural systems is not synonymous with low input agriculture, especially in resource-based subsistence farming where soils are low in nutrient reserves and have been degraded by fertility mining practices. In fact, traditional systems are unsustainable because of none or low off-farm input. Most traditional systems lead to depletion of nutrient reserves, and reduction in soils productivity due to severity of degradative process e.g. accelerated erosion, leaching, depletion of soil organic matter content etc. Sustainability of such system can only be achieved by transformation of subsistence farming to commercial agriculture through judicious and discriminate use of off-farm inputs e.g. inorganic fertilizers, organic amendments, mulching with crop residue, and use of appropriate crop species and improved cultivars.

Appropriate land use is an important aspect of agricultural sustainability. An ecologically compatible land use system is the one that, in addition to enhancing agronomic and economic productivity, also maintains an increasing or a non-negative trend in water quality, carbon sequestration, biodiversity and environmental regulation capacity (Fig. 3). An ecologically compatible landuse system should enhance productivity without jeopardizing environmental quality. In fact, the objective of management is to enhance productivity and environmental regulatory capacity.

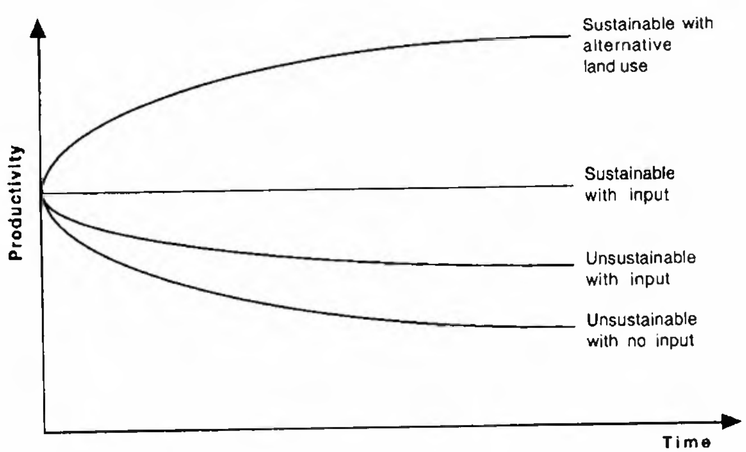

Figure 2. Concepts in agricultural sustainability in the context of SSA.

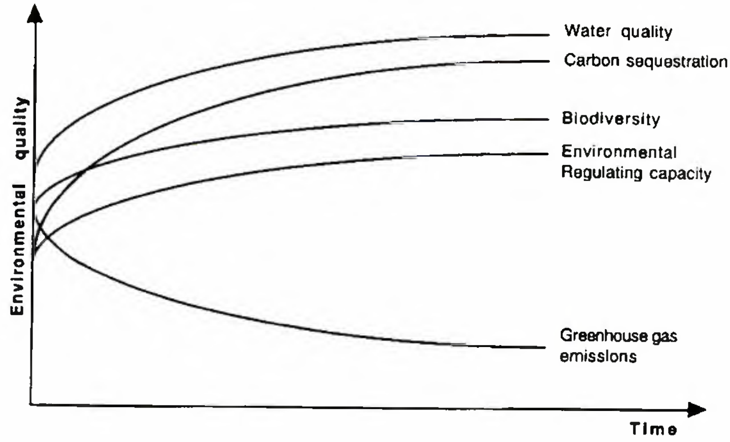

Figure 3. Ecologically compatible land use.

SOIL QUALITY AND RESILIENCE

Soil degradation, diminution of soils productivity and environmental regulatory capacity, is set-in-motion by adoption of ecologically incompatible landuse and fertility-mining. Soil quality refers to attributes or characteristics that affect productivity and environmental regulatory capacity. Soil quality depends on the effects of soil physical, nutritional and biological attributes, and interaction with biological and socio-economic environment (Fig. 4). Soil degradative processes, set-in-motion by incompatible landuse and soil mismanagement for a long period of time, lead to decline in soil quality and its actual and potential productivity. Soil quality, therefore, is a function of soil attributes and management (E_q 1).

$$S_q = f(S_a, C_p, M_i) \text{ ---------------------- } (E_q\ 1)$$

Where S_q is soil quality, S_a is soil attributes, C_p is crop productivity Mi is management input, and t is time. However, there is generally a poor correlation between soil quality and productivity, because productivity depends on management, inputs and micro- and mesoclimate. Ecologically compatible landuse and science- based management enhance soil quality and productivity.

Susceptibility to degradative processes depends on soils resilience. The latter is defined as soils ability to recover or restore its life-support processes following natural or anthropogenic perturbations and depends on the balance between degradative and restorative processes (E_q 2).

$$S_r = S_a + (S_n - S_d + I_m)_t \text{ ------------------------- } (E_q\ 2)$$

where S_r is soil resilience, S_a is antecedent condition, S_n is the rate of new soil formation, S_d is the rate of soil depletion, Im is the management input and t is time (Lal, 1993_a). Generic equations 1 and 2 can be made soil-specific with reference to the most critical or limiting factor(s). The

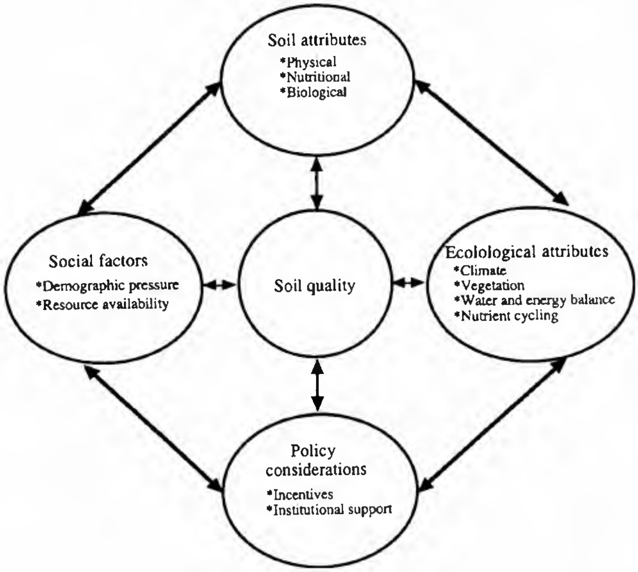

Figure 4. Interactive effects of biological, ecological, social and policy considerations on soil quality.

critical factor may be rooting depth, soil organic matter content, plant available water reserve, soil pH and total acidity, or plant available nutrient reserves (Lal 1994a). Soil-specific relations are usually empirical and should be based on well-designed and properly monitored long-term experiments (Aune & Lal 1995).

Comparative evaluation of soil resilience, soil quality, and soil degradation is shown in Table 1. Soil resilience is affected by the parent material and pedogenetic factors, soil quality by soil attributes, and soil degradation by soil management and climatic or ecological environments. Agronomic or economic productivity is related more to management (endogenous factors) and to climate (exogenous factors) than to soil resilience. In general, however, agronomic productivity is positively correlated with soil quality and negatively with soil degradation. Similarly, relation to environmental regulatory capacity is related more to soil degradation than to soil quality or resilience. Degradative processes have strong and adverse impact on the environment. For example, water quality and gaseous composition of the atmosphere depend on the nature and degree of soil degradation. Accelerated soil erosion affects the magnitude and nature of dissolved and suspended loads in surface water. Water retention and transmission characteristics of soil and management affect the magnitude and type of pollutant transport in the seepage water. Soil degradation also determines the nature, rate, and magnitude of gaseous flux from soil to the atmosphere. When perturbed, resilient soil has a capacity to attain the initial conditions while non-resilient soils may go through irreversible alterations in soil characteristics and their productive capacity.

RESEARCH PRIORITIES

Considerable progress has been made in characterizing soil resources of SSA, and in understanding their potential and constraints. The knowledge gained has replaced several popular myths with scientific facts (Lal & Sanchez 1993). We now know basic principles of soil management for obtaining high yields. Soil related constraints to productivity have been identified (Stewart et al. 1991, Sanchez 1994), and on-station research have developed management systems to overcome these constraints (Lal 1986). However, those results have neither been translated into practical technology nor adopted by the farming community to increase agricultural production. Despite the progress made in understanding soil characteristics and advancing scientific knowledge, per capita agricultural productivity in SSA has declined and soil resources have been severely degraded. Therefore important resource management issues are:

- Why has the knowledge gained and information available on improved scientific technology not been widely adopted by the farming community?

- Why are the soils of SSA easily degraded?

Table 1. Comparison of soil resilience, soil quality and soil degradation.

Attributes	Soil resilience	Soil quality	Soil degradation
1. Factors affecting it	Parent materials, antecedent soil properties, rate of new soil formation, rate of soil depletion, soil management	Soil properties, climate, management input, landuse	Soil properties, landuse, management input, climate, socio-economic and political factors
2. Relation to productivity	None or positive depending on management	None or positive depending on management and climate	Negative depending on degree of degradation and management
3. Relation to environmental regulation capacity	Positive depending on management and antecedent properties	Positive depending on management and ecological environment	Negative depending on degree of soil degradation
4 Effect of perturbation	None or transient	None	High

- Is it feasible to reconcile high productivity and sustainability with environmental quality?

- How can the yield or productivity be increased on prime agricultural land so that pressure on marginal lands can be decreased?

- How can research programs be made out-put oriented and problem solving? and

- How can farmers be made part of the planning processes for research and development?

These are important issues and require inter-disciplinary and multi-institutional team approach to prioritize research and development agenda. Soil management research has an important role to play in addressing soil-related constraints to production and degradation of natural resources. Important researchable issues in sustainable management of soil and water resources are the following:

Soil fertility, enhancement and nutrient management

The single-most important factor limiting crop yields in much of the SSA among resource poor farmers is soil infertility. Unless soil fertility is restored in these areas, farmers will gain little benefit from the use of improved varieties and more productive cultural practices (Borlaug, 1994). Maize yields in Tanzania (905 kg ha^{-1}, FAO, 1984) are among the lowest in Africa and apparently have been declining. Low fertilizer consumption, estimated at 6.7 kg ha^{-1} N+P+K in 1985, could partly account for the low yields. The declining yields are, however, to a large extent due to declining soil fertility, shortage or imbalance of nutrients, inadequate fertilizer and increasing soil acidity due to continuous cultivation (African Academy of Sciences 1987). Evidence based on information from farming surveys indicated that most farmers in Tanzania, are experiencing a general decline in crop yields which they attribute to declining soil fertility (Mnkeni 1992)

With increasing urbanization there is a net transfer of soil nutrients from the countryside to the cities, breaking traditional nutrient cycling practice among smallholders in many areas of Tanzania. Mnkeni(1992) reported that in all cropping systems, more nutrients were leaving the system than were being added. The trend varied from one cropping system to another depending on how crop residues are handled. Nutrient drains are highest in the maize/beans system of Kilimanjaro region and in parts of the plateau zone where nearly all crop residues are used as livestock feed. "Nutrient mining" could, therefore, be mainly responsible for the decline in soil fertility and productivity in many agroecosystem of Tanzania.

In a Keynote Lecture to the 15th World Congress of Soil Science, Borlaug (1994) stated that more than any other region of the world, agriculture south of the Sahara is in crisis. High rates of population growth and little application of improved production technology has resulted in declining per capita food production, escalating food deficits, and deteriorating nutritional levels, especially among the rural farmers. Unless production trends are drastically altered, sub -Saharan Africa will only be producing 75% of its food requirements by the year 2000. He further said that his views are not in line with some environmentalists, social scientists and a few agricultural researchers especially from privileged countries that the next step for small-scale African farmers toward improving soil fertility and crop production is to introduce so called low-input technologies. While such low-input approaches have some appeal, they nonetheless have serious drawbacks. An important one is that low-input technologies often turn out to be knowledge intensive, requiring that farmers possess more than the ordinary skills in crop management. A more realistic development sequence, we believe, is to start by introducing improved seed, fertilizer and weed control technology, which is easier to demonstrate and to diffuse among smallholders. Once they have gained experience with the new technology, they may then be more likely to adopt more knowledge-intensive practices.

While reviewing the work on some long-term experiments conducted in Eastern Africa (mainly from Tanzania and Zambia) Singh & Goma (1994) showed that the sustained crop production in soils of Eastern Africa was dependent on soil-crop conditions. For example, continuous monoculture of maize on the Oxisols even with appropriate use of lime and plant nutrients could not produce sustained high yields whereas Alfisols under similar management conditions were able to maintain high yields of maize. They further pointed out that the addition of lime of appropriate type and in right quantity was essential for sustained crop production in these soils.

To properly address these problems requires a careful planning for research and development priorities which may provide better fundamental understanding of what happens to soils when they are brought under continuous cultivation and which of the cropping systems are able to maintain a sustained production in these highly fragile soils?

Water conservation and management

Water resource of SSA are limited, and drought stress or lack of adequate water supply can be a major production constraint even in soils of the humid tropics. Plant available water reserves are adversely affected by low effective rainfall, decrease in retention, porosity of the root zone and other factors limiting the efficient use of water reserves.

Rainfall effectiveness can be increased by: (i) decreasing runoff (ii) increasing soil water storage (iii) decreasing losses due to evaporation, and (iv) increasing effective rooting depth. Basic principles of achieving all these aspect are known, and on-station experimentation have shown significant improvements in soil water storage in the root zone with concomitant increase in crop yield. However, major research priority lies in conducting on-farm experimentation based on farmer participatory research in practical aspects of soil water management e.g. ridge tillage, mulch farming, conservation tillage etc. Presence of root-restrictive layer in the profile can limit use of water reserves available in the sub-soil. In addition to physical barriers, lack of or low level of available P and Ca in the sub-soil can also be a major factor adversely affecting root penetration into the sub-soil (Sanchez 1994, Smaling 1991). Since increasing P availability can improve root development and water uptake in the sub-soil, it is important to develop appropriate methods of enhancing P reserves of sub-soil. The same argument applies for enhancing availability of Ca in soils of high acidity and low base saturation.

Identifying and using appropriate methods of soil tillage and seedbed preparation is a researchable priority. There is a need to develop a soil guide in relation to identifying suitable methods of seedbed preparation (Lal 1985). Suitable method may be ridge tillage and plow-based tillage for soils of low infiltration rate in arid and semi-arid regions, and mulch farming and reduced or no-till system for soils of humid and sub-humid regions.

Supplemental irrigation is an important aspect of water conservation and management and may be achieved through use of surface water, ground water or water harvesting techniques. There is a large unexploited irrigable potential in SSA that has not yet been realized. Only 2% of the irrigable land in SSA is currently been irrigated (Lal 1993b). Although capital intensive, it is important to develop economic and ecologically compatible methods of expanding irrigable land area in SSA .

Minimizing risks of soil degradation

Soil degradation is a widespread problem in SSA (Oldeman 1991-92) with 14 million ha affected by physical degradation and 62 million ha subjected to chemical degradation. Land area prone to accelerated soil erosion in SSA is estimated at 227 million ha by water erosion and 186 million be by wind erosion. Subsistence and low-input or resource-based agriculture is the principal cause of accelerated erosion and other forms of soil degradation in SSA. It is important, therefore, to identify policy considerations that facilitate transformation of resource-based subsistence farming into science-based commercial agriculture. There are few, if any, reliable estimates of the impact of erosion on crop yields at continental scale in SSA (Lal 1994b). This information is not available for principal soils and important crops of the region. An important strategy is to assess the economic impact of erosion in term of loss in productivity. On-site effects of erosion on crop yields should be evaluated for different crops, cropping systems and management inputs for principal soil and ecoregions of SSA. These experiments should be conducted under farmer conditions by identifying soil phases affected by different levels of past erosion (Lal 1987).

Restoration of degraded soils

Cost-effective and simple methods need to be developed for restoring productivity of degraded soils. In addition to developing practical technology, based on judicious use of inorganic fertilizers and organic amendments involving biological measures, it is also important to identify critical limits of soil properties. Important soil properties to be considered are soil depth, available water capacity, pH, exchangeable Al and total acidity, soil organic carbon content, and ECEC (Lal 1994b). It is crucial to establish those limits for major soils, major crops and principal ecoregions of SSA.

Restoration of degraded soils would involve massive inputs of chemical fertilizers and supplemental irrigation. It is, therefore, important to identify policy issues that facilitate easy and timely availability of fertilizers, amendments, and irrigation facilities. In addition, change of landuse is also an important aspect of soil restoration. Restorative landuse may mean change from arable landuse to silviculture, pastoral land use, agrisilvicultural, or agripastoral-silvicultural system. Once again, policy issues need to be identified and proper incentives given to facilitate change in landuse.

Farmer participatory Research

For facilitating widespread adoption of improved technology, it is important to involve farmer in the planning process (Kasseba 1994). Research in soil and water conservation and fertility enhancement should be done under farmer conditions with farmer managed experiments. The choice of treatments to be tested should be made in consultation with farmer. In addition to a wide range of technological options, two important treatments to be included are: (i) farmers practice and (ii) the best management technologies regardless of its economic feasibility under prevalent socio-economic and political conditions. Evaluation of these two treatments is essential to determine the potential productivity of these soils under best management practices, and to create awareness among farming community of what is achievable given the availability of essential inputs. Planning and implementation of these experiments should be done on a regional basis by interdisciplinary and multi-institutional teams. Such teams should involve agronomists, soil scientists, economists, plant breeders, anthropologists, political scientists, and farmers.

CONCLUSIONS

There is a need to re-evaluate strategies for achieving agricultural sustainability in SSA, where sustainable agriculture is not synonymous with the low-input agriculture. There is a need to create awareness about the dangers of perpetuating the myth that high level of productivity can be achieved and sustained with none or low-inputs in these impoverished soils in ecologically-sensitive regions. Enhancement of nutrient reserves, especially of P and N, is essential to increasing productivity. Supplying large amounts of these essential nutrients at the rate of 50 to 100 kg ha^{-1} cannot be easily done through application of organic manures. While inorganic fertilizers are expensive and not readily available, effort must be made to facilitate their availability, readily on time, and at affordable prices. Improving irrigable land area is another important priority that needs immediate attention. Massive problems of feeding 500 million inhabitants of SSA require drastic measures of improving soil productivity through science-based inputs.

It is also important to reconcile productivity and sustainability with environmental quality. Agricultural sustainability, an increasing trend in per capita, productivity can be achieved without degrading environment through judicious and discriminate use of science-based inputs. It is the widespread use of subsistence agricultural practices that lead to soil and environmental degradation, exacerbate poverty and malnutrition, and perpetuate crises and sub-standard living.

Considerable body of knowledge exists regarding management of soil fertility and conservation of soil and water resources. However, these data from research station experiments have not been translated into practical technology that can be readily used by the farmer. That is one of the reasons of low rate of adoption of improved technology in SSA.

Therefore, important researchable priorities are:

- Characterization of soil fertility and study of the dynamics of soil properties: chemical, physical and microbiological.

- Understanding the long-term effects of organic matter enhancement in soils dominated by low activity clay (Oxisols and Ultisols) on reducing soil acidity, nutrient economy, and soil conservation is required.

- Understanding of acid soils problems in relation to nutrient management and root development is essential. Management technologies involving plant adaptation to acid conditions and low inputs should be developed.

- On-farm evaluation of best management practices with farmer-managed experimentation,

- Identification of soil and crop management technologies that minimize risks of soil and environmental degradation and improve biomass production,

- Assess economic impact of soil degradation in terms of loss of yield for different levels of inputs for major soils and principal crops. The economic impact should be assessed on regional basis,

- Develop cultural practices for restoration of degraded soils. These practices should be based on interdisciplinary and multi-institutional teams, and

- Identify policy considerations that facilitate adoption of improved technology.

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