Working Paper No.

PN-ABE-225
64567

Working Papers are made available in limited numbers for comment and discussion and to inform interested colleagues about work in progress at the International Council for Research in Agroforestry. Comments and suggestions are invited, and they should be directed to the author(s).

ICRAF

INTERNATIONAL COUNCIL FOR RESEARCH IN AGROFORESTRY
CONSEIL INTERNATIONAL POUR LA RECHERCHE EN AGROFORESTERIE
CONSEJO INTERNACIONAL PARA INVESTIGACION EN AGROSILVICULTURA

P.O. Box 30677, Nairobi, Kenya, Tel: 29867. Telex: 22048 Cable: ICRAF

PN-ABE-225
64567

ICRAF WORKING PAPER NO.

44

THE POTENTIAL OF AGROFORESTRY FOR SOIL CONSERVATION

PART III. SOIL CHANGES UNDER AGROFORESTRY (SCUAF): A PREDICTIVE MODEL

Anthony Young, Rodney J. Cheatle and Peter Muraya

March 1987

CONTENTS

		Page
	PREFACE	iv
	ACKNOWLEDGEMENTS	iv
	ABSTRACT	1
1	INTRODUCTION	2
1.1	General	2
1.2	Objectives of SCUAF	2
1.3	Choice of the carbon model	4
2	STRUCTURE AND FUNCTIONING OF THE CARBON MODEL	5
2.1	Basis of the model	5
2.2	Overview of the model	6
2.3	The plant compartment	9
2.4	The soil compartment	11
	2.4.1 General	11
	2.4.2 Humus fractions	11
	2.4.3 Choice between one- and two-fraction assumptions	13
2.5	Modelling of erosion	14
	2.5.1 General	14
	2.5.2 The tree proportionality factor	15
	2.5.3 Change in erosion with time	16
2.6	Feedback effects of soil changes on plant growth	17
2.7	Default values	19
3	INPUTS AND OUTPUTS	23
3.1	The menu	23
3.2	Inputs	23
3.3	Outputs	25
3.4	Saving and loading runs of the model	27
3.5	Graphical output	27
4	TECHNICAL ASPECTS	36
4.1	Computer hardware and software	36
4.2	The SCUAF program	36
	4.2.1 General	36
	4.2.2 Initialization of system variables	38
	4.2.3 Inputs	38
	4.2.4 Outputs	40
5	EXAMPLES AND APPLICATIONS	43
5.1	Introduction	43
5.2	Data availability	43
5.3	A spatial zoned system: alley cropping	44
5.4	A rotational system: shifting cultivation	48
5.5	Sensitivity tests	52
5.6	Applying SCUAF to non-agroforestry land use systems	55
5.7	Applying SCUAF to complex agroforestry systems	60

			Page
5.8	Using SCUAF for purposes of agroforestry system design		64
	5.8.1	Introduction	64
	5.8.2	Starting agroforestry research	64
	5.8.3	Modifying existing designs	65
	5.8.4	Collecting data for improved future predictions	66
5.9	A final word of caution		67
6	USER'S GUIDE TO SCUAF		68
6.1	Introduction		68
6.2	Getting started		68
6.3	Inputs		68
6.4	Outputs		80
	6.4.1	Introduction	80
	6.4.2	Outputs giving a record of input data	80
	6.4.3	Outputs showing flows of carbon	81
	6.4.4	Outputs showing changes in soil conditions and plant response	81
	6.4.5	Converting outputs to graphical form	84
6.5	Saving and loading runs of the model		86
REFERENCES			87
APPENDIX			90

LIST OF TABLES

Table 1.	Default values of variables in SCUAF.	20
Table 2.	Specimen outputs from SCUAF.	28
Table 3.	Alley cropping, Ibadan, Nigeria: record of input data.	45
Table 4.	Shifting cultivation, The Philippines: record of input data.	49
Table 5.	Sensitivity test.	54
Table 6.	Effects of removals and additions of organic material on soil carbon after 20 years, for a system initially in equilibrium.	56
Table 7.	SCUAF data input form.	70
Table 8.	Generalized values of the soil erodibility factor (K) for FAO soil classes.	75
Table 9.	Generalized values of the slope factor (S).	76
Table 10.	Generalized values of the cover factor (C).	76

LIST OF FIGURES

		Page
Figure 1.	Simplified outline of the SCUAF model.	7
Figure 2.	Outline of the SCUAF model.	10
Figure 3.	User's view of the SCUAF menu.	24
Figure 4.	Specimen outputs from SCUAF.	33
Figure 5.	The user interface of SCUAF.	37
Figure 6.	Carbon in SCUAF.	39
Figure 7.	Outline of the procedure SIMULATE for calculating annual changes.	42
Figure 8.	Alley cropping, Ibadan, Nigeria: changes in soil carbon.	47
Figure 9.	Shifting cultivation, The Philippines: changes in soil carbon.	51
Figure 10.	Soil carbon under natural vegetation.	58
Figure 11.	Soil carbon and tree growth under reclamation forestry.	59
Figure 12.	Soil carbon and erosion under maize monoculture.	61
Figure 13.	Soil carbon under maize monoculture replaced by agroforestry.	63

PREFACE

The present text of this review, as three working papers, is intended as a draft version prior to subsequent publication in book form. Work of significance has no doubt been omitted. Readers are earnestly invited to comment on matters of fact, interpretation or emphasis, and to give details of relevant publications, reports and work in progress.

Anthony Young
Nairobi, March 1987

ACKNOWLEDGEMENTS

The review of the potential of agroforestry for soil conservation, of which the model described in this Working Paper is one output, was supported by a grant from the Swedish International Development Authority. A prototype form of the model was developed, in Basic language, by Dr. P. M. Hotten. The present model, in MS-Pascal language, was programmed by Mr. P. Muraya. Data abstraction, analysis and modelling during development of the present model was carried out by Mr. R. J. Cheatle.

THE POTENTIAL OF AGROFORESTRY FOR SOIL CONSERVATION

PART III. SOIL CHANGES UNDER AGROFORESTRY (SCUAF): A PREDICTIVE MODEL

ABSTRACT

The paper describes the objectives, structure and functioning of a computerized model for prediction of soil changes under specified agroforestry systems within given environments. It provides estimates of changes in soil organic matter, represented by carbon, and soil erosion, together with the response of plant growth and harvest to soil changes. The model is intended to assist in the design of agroforestry systems, for research or development, by predicting the effects of alternative design and management options. Inputs to the model cover the physical environment, the agroforestry system (spatial or rotational structure, removals) and initial plant growth. Outputs are estimates, for any specified period, of changes in soil humus carbon, erosion, plant growth response, and harvest. Examples of modelling are given, including spatial and rotational systems, and application to non-agroforestry systems. The model operates on MS-DOS/PC-DOS microcomputers and is available on diskette.

1 INTRODUCTION

1.1 General

This paper describes a computerized model designed to predict the effects upon the soil of specified agroforestry systems within given environments. The model is called Soil Changes Under Agroforestry (SCUAF). It covers the prediction of erosion and changes in soil fertility, together with feedback effects of soil changes upon plant growth.

The model arose out of a review of the potential of agroforestry for soil conservation. In this review, soil conservation was interpreted in its wider sense, to include both control of erosion and maintenance of soil fertility. The review of the potential of agroforestry for the control of soil erosion is published as ICRAF Working Paper 42 (Young, 1986b). First results from the study of its potential for maintenance of soil fertility have been given in Young (1985b, 1986a), building upon a previous summary of soil productivity aspects of agroforestry by Nair (1984); further material will appear in ICRAF Working Paper 43 (Young, in preparation). These publications contain more extended discussions of the concepts upon which the SCUAF model is based.

At present, the model is operative for prediction of changes in soil organic matter, represented by carbon, together with erosion. It is being extended to include the cycling of specific nutrients, in the first instance nitrogen.

1.2 Objectives of SCUAF

A basic requirement for land use systems is that they should be sustainable: that is, retain their productive potential over a period of time, through conservation of the natural resources on which that productivity depends. Foremost among the needs for sustainable production is that of maintenance of soil fertility.

It is therefore desirable to be able to predict the effects upon the soil of specified agroforestry systems, within given environmental conditions, and to compare these with the effects of other land use systems. We know that in many tropical environments, continuous arable agriculture with low inputs degrades the soil; and conversely that natural vegetation, and some forest plantation systems, maintain soil fertility. If it can be shown that a given agroforestry system is at the same time productive and has the capacity to maintain soil fertility in a steady state, or to assist in the recovery of a degraded soil, then such a system is clearly worthy of development.

It was with this goal in mind that an attempt was made to prepare a model to predict soil changes under agroforestry. It soon became apparent that there were two difficulties in achieving this objective: shortage of data and lack of knowledge about processes. The data required are on the quantitative performance of agroforestry systems, particularly rates of plant growth and soil changes over time, obtained from field trials.

The processes about which more knowledge is required are those involved in plant/soil cycles of organic matter and nutrients, and their loss from the soil.

A computerized model is demanding in its requirements, both for a full set of data and for precise specification of calculation procedures. It makes no tacit assumptions, cannot calculate vaguely-specified functions, nor operate with missing data.* It became apparent, both in specifying the functioning of processes within the model and in attempting to input the best available sources of data, that substantial further research was necessary before a desirable level of confidence in predictions from the model could be obtained. This finding is in itself a useful result; it draws attention to critical areas for research, both on soil processes in general and on agroforestry systems in particular.

Notwithstanding these problems, some degree of prediction can be made on currently available data. This is achieved by taking land use systems of which the impact on soils is known, and using these as a basis for studies of agroforestry. Data can be drawn from plant/soil carbon and nutrient cycling studies under natural vegetation, agriculture and plantation forestry. This is the approach that has been employed in the development of the model.

Having obtained a model for making approximate predictions, it can be employed as a design tool. Field trials are costly to run and, since agroforestry depends on the growth of perennial trees, are slow to give results. Any method of improving the chance that a given system will have the desired performance is therefore welcome. The use of the model for design purposes is discussed further in Section 5.8.

Thus the objectives of the model are:

i. To make approximate predictions of the effects upon the soil of specified agroforestry systems within given environments.
ii. To show what data are needed from agroforestry experimental work if such predictions are to be made.
iii. To make use of these predictions as a tool in the design of agroforestry systems, either for selecting the most promising systems for initial trials, or for improving systems for which some data on performance are available.
iv. To indicate what improvements in knowledge of plant/soil and soil processes are needed in order to improve the accuracy of such predictions.

And thus, as the long-term goal arising from studies based on objectives ii and iv:

v. To improve the accuracy of predictions of the effects upon the soil of specified agroforestry systems within given environments.

* There is a specialized technique, that of "fuzzy data sets", which permits a degree of imprecision.

1.3 Choice of the carbon model

There have been many attempts to model soil-plant cycles, both of organic matter and nutrients. The most numerous have been models of the nitrogen cycle, but there has also been substantial work on modelling of the carbon and phosphorous cycles, and somewhat less on the cycling of potassium and micronutrients (for reviews, see Frissel, 1977; Frissel and van Veen, 1982; Bolin and Cooke, 1983). In addition, there are at least four models for the prediction of soil erosion (see Young, 1986b, pp. 13-20).

It is clearly essential for present purposes to include the effects of soil erosion. Given this, it was intended to develop models for cycling of carbon (as representing organic matter), nitrogen and phosphorus, at first separately and then combined. It soon became apparent that the time requirements were considerable, and a choice had to be made on the first cycle to be developed. Nitrogen is the major nutrient deficiency in the tropics. Arguments in favour of giving it priority are the existence of relatively large amounts of data (at least on some parts of the cycle) and that nitrogen fixation is a recognized benefit from many agroforestry systems. Problems with nitrogen are the complexity of the cycle and the large uncertainties in magnitude of several facets: nitrogen fixation, immobilization and release, denitrification, nitrification and translocation losses.

A model for the cycling of organic matter, represented by carbon, was chosen for development in the first instance for the following reasons:

i. There is an established body of knowledge, albeit with important gaps, on the functioning of the plant-soil carbon cycle.
ii. A substantial amount of data are available, both on rates of plant growth and on soil carbon levels. These data are useful in the calibration of the model.
iii. The effects of soil physical properties on productivity are well established, and organic matter is the main variable factor which affects these properties (Lal and Greenland, 1979). Through physical properties, organic matter also affects resistance to erosion.
iv. There is a degree of parallelism between the carbon and nitrogen cycles; specifically, within the soil, the carbon: nitrogen ratio tends towards 10:1.
v. Much current research and development effort in agroforestry is directed at farming systems with low capital resources and low inputs of fertilizers. A continuing supply of fresh organic matter to the soil, which is progressively mineralized, is a partial guarantee of an adequate nutrient supply.

The results presented here are for what will become the carbon submodel (SCUAF-C). For convenience, however, this will be referred to in this paper as the SCUAF model.

2 STRUCTURE AND FUNCTIONING OF THE CARBON MODEL

2.1 Basis of the model

The starting point for carbon cycling models is the classic work on the soil under shifting cultivation by Nye and Greenland (1960). Based upon this foundation, plant-soil carbon cycles for three types of natural vegetation, rain forest, moist savanna and dry savanna, were given in Young (1976, pp. 108-114). An adaptation of the same model to cereal cultivation and to a system with both tree and crop components is given in Young (1985b, pp. 11-19). Other carbon cycling models taken into account included those of Bernhard-Reversat et al. (1975), Jenkinson and Rayner (1977), Smith (1979), van Veen et al. (1981) and Bosatta and Agren (1985). Attention was also given to results from carbon isotope labelling studies and fractions of soil organic matter, reviewed in Paul and van Veen (1978) and Young (1985b, pp. 19-21).

More generally, the concepts and evidence on which the present model is based are those discussed in the associated review of the role of agroforestry in maintenance of soil fertility (Young, in preparation). The present paper does not attempt to repeat this discussion, but is limited to comments which seek to explain or justify the decisions taken in the construction of the model.

Features of the model are its intentional simplicity, operation on an annual time basis, iterative functioning, the omission of specific calculation of the carbon held within the soil microbial biomass, and a design specifically directed at agroforestry systems.

A relatively simple model was aimed at for two reasons. First, since the processes involved in some parts of the cycle are very imperfectly known, little purpose is served in constructing a model of great refinement. Secondly, it is intended that the SCUAF model shall be used for practical development of agroforestry systems, which is less likely if there is a high degree of complexity. An adjunct to simplicity is transparency, meaning that the functioning of the model is intended to be clear to users. This is an essential feature in any model intended for use by other than its designer.

The model operates on an annual basis; that is, the smallest unit of time considered is one year. This is partly in the interests of simplicity, and partly because the aim is to determine the sustainability of land use systems, and thus to estimate soil carbon changes over a number of years.

Operation of the model is iterative, by whole years, as opposed to continuous. Conditions at the beginning of year t are used as the basis to calculate processes and changes during year t, leading to conditions at the beginning of year t + 1. The "beginning" of a year may be variously interpreted according to circumstances, commonly as the dry season when no annual crops are growing. A model with an alternative basis, that of continuous functions, is described by Bosatta and Agren (1985).

It would have been possible to take soil microbial biomass as a carbon store, with calculation of flows into it and out. Such flows are important where seasonal changes are concerned, but on an annual basis they nearly balance out. Biomass typically constitutes only 2-4% of the organic carbon in tropical soils (Jenkinson and Ladd, 1981). Thus, whilst soil fauna play a large role in the model, both in litter decomposition and loss of soil carbon by microbial oxidation, the carbon held as biomass within them is not calculated. This contrasts greatly with the complex model described by Smith (1979), in which most of the 43 variables used relate to soil microfauna.

Lastly, the SCUAF model is by definition designed and intended for application to the basic situation in all agroforestry systems, that of the existence of at least two plant components, one of them formed by trees or shrubs.

2.2 Overview of the model

The SCUAF model is shown in simplified form in Figure 1. The plant-soil system consists basically of PLANT and SOIL, with LITTER and SOIL FAUNA as intermediate elements. In agroforestry systems, the PLANT contains TREE and CROP components, each of which is partitioned into LEAF, FRUIT, WOOD and ROOT.

The cycle is divided into plant and soil sections. In the plant section, carbon enters the TREE and CROP from the ATMOSPHERE, by photosynthesis, and is redistributed internally to the parts of the plants. During or at the end of the year, some parts of each plant become HARVEST, a term which covers all removals from the plant-soil system. Other parts remain within the body of the plant as year-to-year GROWTH. What is not removed as HARVEST or retained as GROWTH becomes LITTER. ORGANIC ADDITIONS, such as farmyard manure, may be brought into the system at this point. Litter is decomposed by the SOIL FAUNA, in the process of which there is a considerable carbon loss, as CO_2, by oxidation. What remains enters the soil by the process of humification.

In the soil section of the model, the store is the SOIL. Carbon is added to the soil from the plant section by humification. It is lost as further oxidation, by soil microfauna, and by erosion. Thus:

Soil carbon in Year t = Soil carbon in Year t-1
+ additions from humification
- loss by oxidation
- loss by erosion

Looked at in more detail, there are two plant components, TREE and CROP. TREE refers to the tree or shrub component, present by definition in all agroforestry systems. CROP normally refers to the herbaceous plants in the system, which may be agricultural crops or, in sylvopastoral systems, pasture plants; it is possible for CROP to refer to a woody perennial, as in systems such as shade trees over coffee or tea. Where, as is frequently the case, more than one species of tree or crop are present, their rates of biomass production are summed prior to input to the model.

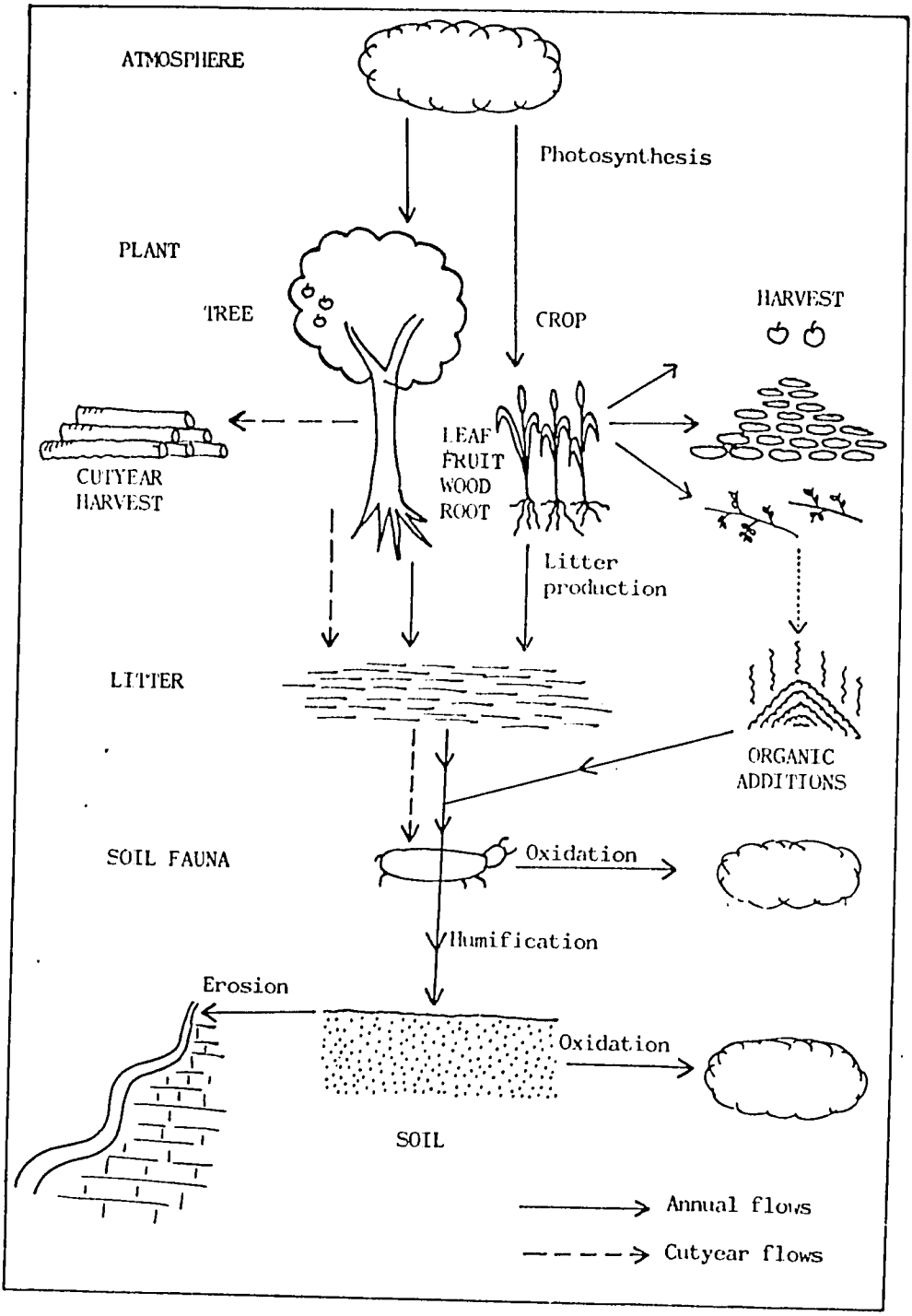


Figure 1. Simplified outline of the SCUAF model.

The structure of the agroforestry system may be either spatial or rotational. If spatial, the proportions of ground surface occupied by the TREE and CROP components are specified, e.g. 0.2 and 0.8 respectively in a typical alley cropping system. These proportions need not add up to 1.0; in a dense tree stand with pastures beneath, for example, they might total close to 2.0, both components occupying nearly 100% of the land. If the system is rotational, the number of years under TREE and CROP components is given, and which comes first. The model does not at present permit combined spatial and rotational systems, such as the taungya practice (but see Section 5.7).

The plant components are divided into four parts, LEAF, FRUIT, WOOD and ROOT. LEAF includes all herbaceous matter, including the stems of many crops. FRUIT covers all reproductive matter, including the grain of cereal crops. WOOD includes both trunk and branches; it is absent from the crop component except where this is a woody perennial, such as coffee. ROOT covers below-ground biomass other than harvested tubers, etc., which for modelling purposes are (in some cases biologically incorrectly) assigned to FRUIT. The below-ground stemwood of trees may be allotted to either WOOD or ROOT at the discretion of the user.

LITTER refers to all plant residues that are not removed from the system, i.e. that become decomposed by soil fauna. It thus includes, in addition to litter in its narrower sense of fallen leaves, tree prunings and crop residues if these are returned to the soil, and root exudates and residues.

As noted above, SOIL FAUNA are important as a process, but the magnitude of the carbon held in their biomass is not calculated in the model.

SOIL can refer to the whole soil profile or to the topsoil only, at the choice of the user. It is treated as a single entity, in which the carbon present is summed; there is no provision for calculating separately the carbon in two or more horizons, nor flows between them.

TREE, CROP, LITTER and SOIL together form the plant-soil system. External to that system are carbon sources and sinks.

The carbon sources are ATMOSPHERE and ORGANIC ADDITIONS. ATMOSPHERE is the primary source of plant and soil carbon, through the process of photosynthesis. ORGANIC ADDITIONS refers to organic material, such as grass mulch, compost and farmyard manure, that is brought into the system from outside.

The carbon sinks in the model are ATMOSPHERE, HARVEST, CUTYEAR HARVEST and RIVER. Carbon is returned to the ATMOSPHERE by oxidation as CO . HARVEST refers to all removals from the system; many of these are harvest in the normal sense, but losses from burning and livestock browsing directly from the plant components may also be included.

In many agroforestry systems, the tree component is allowed to grow for a number of years and then felled, coppiced or pollarded. The year in which this different management takes place is called a cutyear. Any additional harvest during such years, commonly of fuelwood, is the CUTYEAR HARVEST. There may be additional flows of dead plant material to the soil, e.g. root residues, during a cutyear.

It may be argued that the feeding of tree leaf litter to livestock and its return to the soil as farmyard manure does not constitute a removal from an agroforestry system. These flows could have been modelled by a conversion factor relating fodder to manure, the factor being permitted to exceed 1.0 where the livestock were fed substantially on material of external origin. However, other factors arise in systems with a livestock component, and pending possible further development of the model, livestock are treated as an external element. Thus it is possible in SCUAF to feed plant residues to livestock off-site and return farmyard manure to the system--- but the transfer must be made by hand!

2.3 The plant compartment

Figure 2 shows the model in more detail. The starting point is the annual net primary production (NPP) of biomass, expressed as dry matter. This refers to above-ground production, because very few studies to date measure root production. The NPP is partitioned by default according to the values shown, e.g. the crop into 67% leaf and 33% fruit (at time of harvest). However, observed data on plant parts are frequently available.

By default, roots are assumed to be 40% of above-ground NPP. Thus the total plant biomass consists of roots additionally to NPP. However, if only the topsoil is being considered, a proportion of the root biomass will enter the deeper soil horizons.

At this point, dry matter, the unit in which plant biomass production is normally expressed, is converted into carbon. Unless the user specifies otherwise, the conversion factor is 0.5 for all plants and parts.

The plant compartment continues as described above, with accumulation as growth within the system, and harvest and other losses external to it. The additional cutyear harvest is subtracted from accumulated growth. This leads to annual and additional cutyear flows of litter, to which are added the carbon in organic additions. At this point, there are potentially 18 flows of dead plant material:

tree and crop
x leaf, fruit, wood, root
x annually and in cutyear
+ organic additions to tree and to crop.

Some of these will be of zero value, e.g. all crop fruit is likely to have been harvested.

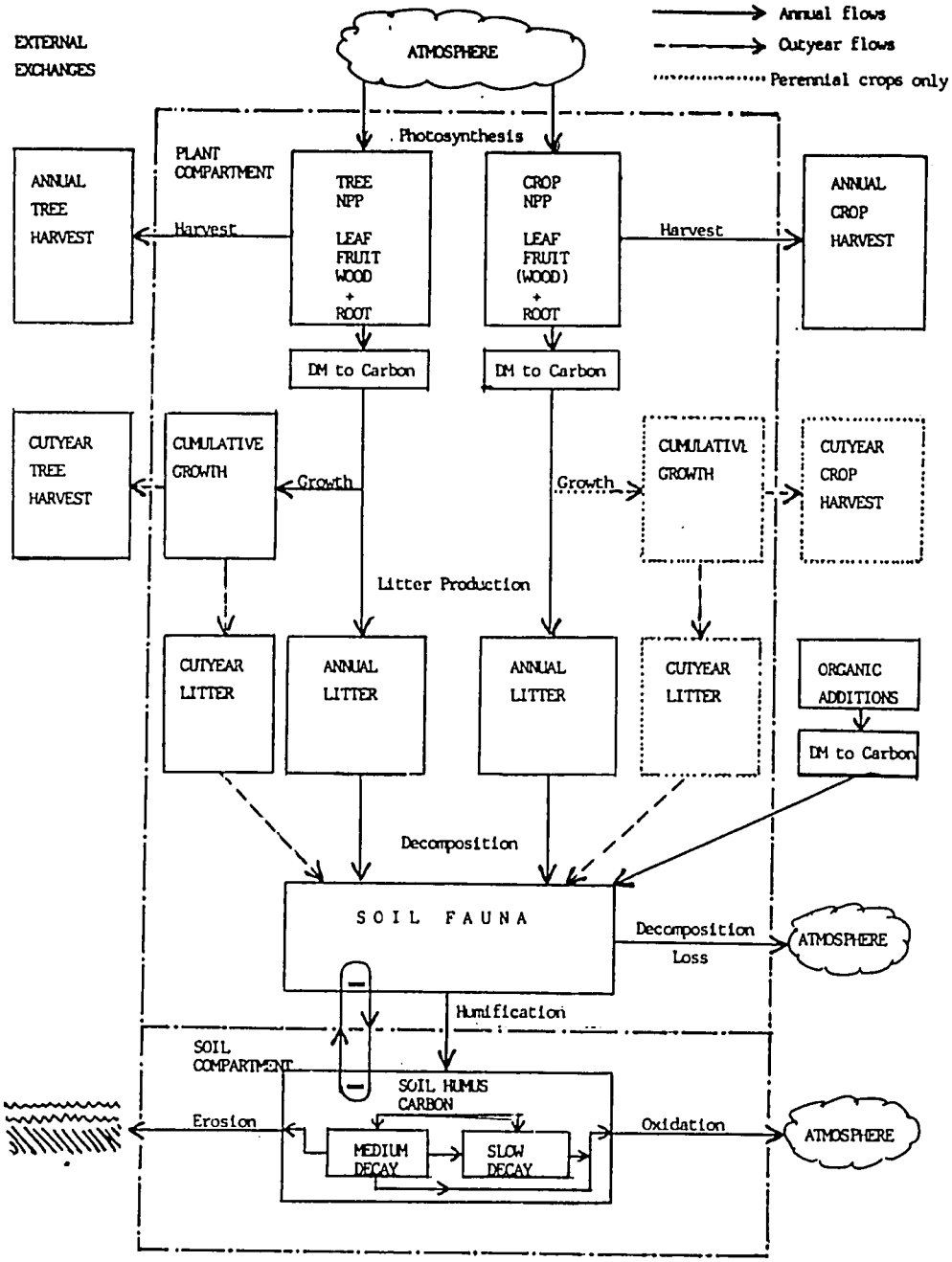


Figure 2. Outline of the SCUAF model.

The process shown in Figure 2 as humification conversion loss requires discussion. In the model of Nye and Greenland it was regarded as a simple proportional loss: "The proportion of fresh material converted to soil humus will probably lie between about 1/10 and 1/5....(and of roots) between 1/5 and 1/2" (Nye and Greenland, 1960, p.50). In carbon-isotope labelling studies, no hard-and-fast distinction is made between carbon in the forms of plant litter and soil humus. These studies show that in the tropics, some 65% of labelled plant litter is lost within 5-6 months of being added to the soil. It seems likely that this corresponds to the conversion loss in the Nye and Greenland model.

If this fast-decaying matter were considered as a humus fraction with a short half-life, then soil analyses would show a clear annual fluctuation in humus content. As they do not, it may be assumed that such matter is still in a state in which it is removed by pre-treatment prior to soil carbon analysis. The present model therefore treats this as a conversion loss, placed within the plant compartment. Default values of 0.85 loss (i.e. 15% conversion) for above-ground litter and 0.67 loss (33% conversion) for roots are assumed; this is the least securely-based feature of the cycle.

2.4 The soil compartment

2.4.1 General

The annual balance of soil humus carbon, C, is given by:

$$C_{t+1} = C_t + \text{additions} - \text{oxidation} - \text{erosion}$$

where t and t+1 are successive years;
additions are from litter (Section 2.3);
oxidation is loss of CO_2 by soil fauna (Section 2.4);
erosion is loss of carbon in eroded soil (Section 2.5).

2.4.2 Humus fractions

Soil humus is of a variable nature. In particular, some humus fractions decay very much more slowly than others. Most accounts, including isotope-based studies, treat this situation by recognition of two or more discrete fractions with different properties; as many as five fractions have been recognized (Jenkinson and Rayner, 1977). An alternative approach is in terms of a continuous variation in properties (Swift et al., 1979; Bosatta and Agren, 1985).

The SCUAF model permits use of up to two fractions, called medium-decay and slow-decay humus ("fast-decay" being thought of as the humification conversion loss). Medium-decay humus is the fraction treated in the Nye and Greenland (1960) model, with an oxidation loss, or decomposition constant, of 3-4% per year. This is equivalent to a half-life of some 20 years. Slow-decay humus is the fraction with an unknown but very much slower rate of decay.

The Nye and Greenland model is based on one humus fraction and uses an equation of the form:

$$C_{t+1} = C_t - kC_t \quad \text{or} \quad C_{t+1} = C_t\ (1 - k)$$

where k is the decomposition constant expressed as a fraction, e.g. 0.03. This equation operates for time periods of whole years. For shorter periods, the relation is more precisely expressed by an equation of exponential form:

$$C_{t+1} = C_t.e^{-rt}$$

where e is the exponential constant and r is a parameter. For values of less than 0.1, k and r are nearly equal. The half-life, HL, of humus is given by:

$$HL = \ln(2)/r$$

where ln(2) is the natural logarithm of 2.

As SCUAF operates by whole years, the equation based on the decomposition constant is used, oxidation loss in year t + 1 being equal to kC_t.

For the slow-decay fraction, the equations are of the same form but the decomposition constant is lower.

For two humus fractions, carbon in year t + 1 is given by:

$$C_{t+1} = C_m\ (1 - k_m) + C_s\ (1 - k_s)$$

where the subscripts m and s refer to medium- and slow-decay humus respectively.

The SCUAF user can choose either a one-fraction or two-fraction humus model, the choice being made as an input.

In the one-fraction model, values of the decomposition constant are set by default at kt = 0.03 under the tree component and kc = 0.04 under the crop component (these being the values under fallow and cultivation respectively in the Nye and Greenland model). These values are reduced to kt = 0.0225 and kc = 0.03 for highland climates. As with all default values, the user may alter them.

In the two-fraction model, medium-decay humus has the same k values as in the one-fraction model, whilst slow-decay humus is assigned by default an arbitrary value of 0.01, i.e. a loss of 1% per year. The user must decide what proportion of the humus carbon initially present in the soil is in slow-decay form, the default value being 0.75.

How does the slow-decay fraction originate? The more widely-held view is that all litter initially becomes medium-decay humus, and the slow-decay fraction originates wholly by transformation from it, through processes of physical and/or chemical stabilization. This is the default assumption in SCUAF. The proportion of medium-decay humus transformed annually to slow-decay form is set arbitrarily at 0.01.

An alternative is that some slow-decay humus originates directly from the more lignin-rich or otherwise resistant parts of plant litter; this possibility is hinted at in Swift et al. (1979). In the two-fraction SCUAF model, the user specifies what proportions of each plant part (in particular, the wood fraction) decomposes directly to slow-decay humus. The assumption by default, however, is zero for all parts.

2.4.3 Choice between one- and two-fraction assumptions

A dilemma for modelling is presented by the situation described above. On the other hand, a slow-decay humus fraction, or fractions, undoubtedly exists in soils. On the other, almost nothing is known about its behaviour, neither origin nor rate of decay. "Oh let us never, never doubt what nobody is sure about" (G.K. Chesterton).

The effects on total soil carbon of assuming the presence of a slow-decay fraction are considerable: this fraction builds up over time to a substantial part of the total carbon present, which then acts as a buffer, slowing down carbon loss.

A way out of this problem lies in the fact that the slow-decay humus fraction is, probably, very little affected by management. It is present, and contributes to the carbon measured in standard laboratory analysis, but its quantity changes little over periods of 10-20 years. Furthermore, since it decays slowly, slow-decay humus releases few nutrients. Its contribution to soil physical properties is not known.

It is therefore largely the medium-decay humus that is of interest from the point of view of sustainability, for this is the fraction that can be changed by land use and practical management measures. The greatest changes in soil carbon take place within the topsoil. Furthermore if, as seems likely, all or most plant litter passes first into the medium-decay form, then most topsoil carbon will be of this type.

Conversely, much of the carbon that reaches the lower soil horizons is likely to be in slow-decay form.

This leads to the following approximation, adopted as a working hypothesis in most runs of SCUAF described here:

- most topsoil carbon is in medium-decay form, and most carbon in lower horizons in slow-decay form;
- management largely affects carbon in the topsoil;
- hence, only the topsoil is considered, and the model is run on a one-fraction assumption.

The user is free to make alternative assumptions: namely, to include carbon in the soil down to any chosen depth, or the whole profile; and/or to run the model on the two-fraction assumption.

2.5 Modelling of erosion

2.5.1 General

Agroforestry experiments on sloping land should measure rates of soil erosion. Where this has been done, the recorded average value is entered into SCUAF, as the value for the initial year.

In planning alternative agroforestry systems for trial, such measurements will not be available, and use must be made of productive methods. Models to estimate soil erosion have been reviewed by Rose (1985) and Young (1986b, pp. 13-19). The universal soil loss equation (USLE) in the most widely accepted, the FAO method the simplest (Wischmeier and Smith, 1978; FAO, 1979, pp. 43-46 and 69). However, there is no need to make a choice between these as they are based on the same equation, differing only in the complexity of calculation of the input factors. A provision to make alternative use of the SLEMSA model (Elwell, 1981) may be added to SCUAF subsequently.

Soil erosion is calculated from the equation:

$$\text{Erosion} = R \times K \times S \times C$$

where R = climate factor (rainfall)
K = soil erodibility factor
S = slope factor (LS in the USLE)
C = cover factor

(K has no connection with the humus decomposition constants, kt and kc.)

Neither the FAO method nor the present model includes the conservation practice factor, P, of the USLE. This factor is only meaningful where the way in which practices are applied is standardized.

In each case, the factors may be obtained either by the simplified methods given in the FAO system (intended for use in estimating average erosion over large areas) or, where data permit, by the more sophisticated methods given in the USLE (intended for estimating erosion on individual farm fields).

When these factors have been entered, the model calculates values of erosion separately for the tree and crop components, and displays them. These values can be over-ridden by entering measured values taken from tree and crop-covered experimental plots.

For rotational agroforestry systems, the values of erosion under tree and crop are used in the respective years under these components.

For spatial systems, the user must now enter the tree proportionality factor, described in the following section. The model then displays the calculated rate of erosion for the system as a whole, which again can be over-ridden by entering a measured value.

Soil carbon loss from erosion The calculation of soil erosion must then be converted into loss of carbon. The first step is to assume that erosion removes an amount of carbon proportional to the carbon content in the topsoil: e.g. 1000 kg/ha soil erosion with a topsoil carbon content of 2% causes a loss of 1000 x 0.02 = 20 kg Carbon/ha. Experimental evidence shows that this is an underestimate: the carbon content of eroded sediment is higher than that of the topsoil from which it originates. This difference is the carbon enrichment factor for eroded soil; recorded values are commonly 2 to 4, occasionally as high as 10. The default value in the model is 2.0.

Changes in soil depth Erosion causes a reduction in soil depth. The effects of this crop growth are very small in the short term, but may become serious where depth is reduced below certain critical levels. The model therefore calculates loss of soil depth from the erosion values, taking an average soil density of 1.5 as the basis.

2.5.2 The tree proportionality factor

Given estimates of the rate of erosion for complete covers of crops and of trees, the question arises, how are these to be combined to estimate erosion in a spatial agroforestry system?

Two limiting values can be envisaged. At one extreme, it can be assumed that erosion within an agroforestry system might be proportional to the rates of soil loss under the tree and crop components multiplied by the proportions of ground which each covers. At the opposite extreme, the tree component might control the erodibility of the system, reducing erosion to the same value as it would be under a pure tree cover. Consider, for example, estimated erosion rates of 1000 kg/ha/yr under trees and 30 000 kg/ha/yr under crops. If tree and crop components each covered 50% of an agroforestry system, the combined erosion rate would lie between 15 500 and 1000 kg/ha/yr, respectively, for the two above situations.

Clearly, the true value will lie somewhere between these extremes: that is, the tree component will partly but not wholly limit the rate of erosion. The degree to which the tree component controls the rate of erosion in a land use system is a new concept, distinctive to agroforestry.

This concept is represented by a tree proportionality factor, T. If erosion is fully proportional to the fractions of ground covered by trees and crops, and the respective rates of erosion under a complete tree and crop cover, the T factor takes the value 0.0, indicating that the trees exert no dominant influence. If erosion within the system as a whole is the same as that under a tree cover alone, the T factor takes the value 1.0, indicating that the tree component in the agroforestry system is completely dominant.

To apply the proportionality factor, the rate of erosion calculated for the tree component alone is multiplied by T, and the rate calculated for the situation fully proportional to areas under trees and crops is multiplied by (I-T). For example , if:

Tree cover = 0.4
Crop cover = 0.6
Rate of erosion under tree component = 1000 kg/ha/yr
Rate of erosion under crop component = 30 000 kg/ha/yr
Rate of erosion proportional to cover =
(1000 x 0.4) + (30 000 x 0.6) = 18 400 kg/ha/yr

Then:

For T = 0.0, Erosion = (1000 x 0.0) + (18 400 x 1.0) = 18 400 kg/ha/yr
For T = 0.5, Erosion = (1000 x 0.5) + (18 400 x 0.5) = 9 700 kg/ha/yr
For T = 0.8, Erosion = (1000 x 0.8) + (18 400 x 0.2) = 4 480 kg/ha/yr
For T = 1.0, Erosion = (1000 x 1.0) + (18 400 x 0.0) = 1 000 kg/ha/yr

The default in SCUAF is set at T = 0.8, a value which it is speculated might hold true for a typical alley cropping system, with tree rows planted along the contour and well-maintained ground vegetation beneath them. For mixed agroforestry systems, such as multistorey tree gardens, it is possible that T may approach 1.0.

2.5.3 Change in erosion with time

The climate factor will fluctuate from year to year, but the model is based on average values. However, the soil erodibility factor may be altered if soil properties change, and the cover factor will be affected by changes in rates of plant growth.

Of the soil properties shown in the USLE nomograph for estimating the soil erodibility factor, organic matter, structure and permeability may change. The model gives no information on structure or permeability, and any changes in these properties are for the most part a response to changes in organic matter.

Hence only organic matter is considered. Inspection of the nomograph shows that for conditions in the middle of the ranges displayed, a rise or fall of 1% in organic matter produces a decrease or increase, respectively, of 0.04 in the value of the K factor. Converted to changes in carbon, a 1% increase in topsoil carbon produces a decrease of 0.069 in the value of K.

As described below (Section 2.6), the model estimates changes in rates of plant growth in response to soil carbon increase or decrease. The cover produced by a plant is assumed to be proportional to its rate of growth; thus, it is known that a high-yielding maize crop gives a greater soil cover than a poor crop. The cover factors as estimated at the start of model run are modified on the basis that:

$$Ct = Co \times (1 + ((NPPo - NPPt)/NPPo))$$

where Co and Ct are the cover factors initially and at time t, and NPPo and NPPt the respective rates of net primary production. Thus a fall in the rate of plant growth of 10% produces a rise in the cover factor of 10%, and vice versa.

Based on data on soil carbon content and plant growth, the model calculates changes in the K and C factors with time. It then takes the fixed R and S factors, and calculates changes in rates of erosion with time. If the user has replaced the initial calculated erosion with a measured value, a correction value based on the direction and magnitude of this alteration is carried forward.

The new rates of erosion apply to a soil with different carbon content. Loss of carbon by erosion is calculated by assuming that topsoil carbon percentage has changed proportionally to soil carbon content. One effect of this is that in cases where the soil is seriously degraded, as under continuous arable cropping, soil erosion continues to rise but carbon erosion rises initially and then falls, as the topsoil carbon content becomes depleted.

2.6 Feedback effects of soil changes on plant growth

The rates of tree and crop growth input to the model are those under initial soil conditions. As the soil properties change, the growth of plants will be affected. This is modelled by means of feedback factors, operating within the annual time cycle of modelling. In the SCUAF carbon model, there are two such feedback effects, resulting from changes in soil carbon and soil depth.

Carbon feedback factors A lowering of soil carbon, and thus organic matter, may decrease rates of plant growth for the following reasons:

- Lowering of organic matter leads to degradation of soil physical properties.

- There is likely to be an associated reduction in available nutrients: soil organic matter protects the nutrients against leaching, and then progressively releases them by mineralization.

The latter effect will be modelled more specifically when SCUAF is extended to nutrient cycling.

Whether the converse occurs, an increase in rates of plant growth with rise in soil carbon, depends on the original state of the soil. If initially in good condition, then rasing the carbon level may not affect plant growth. But if the soil is initially degraded, that is, below the level of sustainable fertility for which it has a potential, then increased rates of plant growth may occur as the organic matter level is raised.

To give the user full scope to include whatever level of soil carbon effect upon plant growth seems appropriate to local circumstances, soil carbon feedback factors are included, for tree and crop, which can be set at any value. If a carbon feedback factor is set at 1.0, then a 1% rise or fall in soil carbon, as compared with initial conditions, results in a 1% rise or fall in rates of tree or crop growth. A feedback factor of 0.5 causes 0.5% change in plant growth per 1% change in soil carbon. With a feedback factor set at 0.0, rates of plant growth remain constant. Thus:

$$NPPt = NPPo \times (1 + (((C \quad - Co)/Co) \times CFF))$$

where NPPo and NPPt are net primary production initially and in year t respectively, Co and C are soil carbon initially and in year t-1, and CFF is a carbon feedback factor. For example, let initial soil carbon be 10 000 kg/ha and initial NPP of the tree 20 000 kg/ha (dry matter), and let the soil carbon fall to 9000 kg/ha. Then with the carbon feedback factor set at 0.5, tree NPP in the succeeding year will be:

$$\begin{aligned} & 20\,000 \times (1 + (((9000 - 10\,000)/10\,000) \times 0.5)) \\ = \; & 20\,000 \times (1 - 0.95) \\ = \; & 19\,000 \end{aligned}$$

If the two-fraction humus model is used, the carbon feedback factors operate on medium-decay humus only. Their default values are set at 0.5 for the tree and 1.0 for the crop.

<u>Soil depth feedback factors</u> Soil erosion decreases the depth of the soil profile. This can reduce rates of plant growth through lowering of available water capacity, reduced ability of the remaining soil to retain nutrients, and ultimately through loss of rooting depth. In the earlier attempts to model the effects of soil erosion, plant growth was assumed to decrease linearly with loss of soil profile depth. This assumption is adopted for the model. The two feedback factors are applied jointly, thus:

$$\begin{aligned} NPPt = NPPo \times & (1 + (((C \quad - Co)Co) \times CFF)) \\ & (1 + (((D \quad - Do)Do) \times DFF)) \end{aligned}$$

where Do and Dt-1 are soil depth initially and in year t-1, and DFF the depth feedback factor.

In most runs of the model, the effects of the depth feedback factors are almost negligible by comparison with those of the carbon feedback factors.

2.7 Default values

In seeking data for initial test runs, it soon became apparent that there are no observational studies which could supply the full set of data needed for the model. Thus, records of above-ground net primary production are common, but of root production comparatively rare. Some reports fail to state facts which are obvious to the authors but not to the reader, such as whether crop residues were returned or removed, or if the site was on level or sloping ground. There may not have been measurements of soil erosion, or of the factors needed to estimate it. Sometimes, typical values may be wanted for environments on which measurements could be, but have not yet been, made. Finally, data on soil processes are not available from normal agroforestry experimental work but must be drawn from specialized studies.

To meet the problem of incomplete data, a system of default values is adopted (Table 1). Where the value of a particular variable is not known, the SCUAF model adopts an estimated value. For example, if net primary production of a tree is known but not its apportionment into plant parts, the model assumes 62% of biomass is wood, 32% leaf and 2% fruit. If there are no measurements of roots, their growth is assumed to be 40% of above-ground biomass for both tree and crop. The soil carbon decomposition constants are assumed by default to be 0.03 under the tree component and 0.04 under the crop.

In many cases, default values vary with environment. Thus, typical rates of plant growth depend on climate, values of (initial) soil carbon on climate and soil texture, and values for the factors of soil erosion on climate, soil and slope. Three basic elements of environment --- climate, soil texture and slope class --- are entered into the model, and these determine what will be the default values of environment-dependent variables.

The default values are by no means intended as statements of what variables "ought to be", still less to take precedence over data known to the user. Rather, they have a role in indicating what data, or estimates, are needed in order for the model to function. In every case, default values are displayed on the screen and the user given the opportunity to change them.

Table 1. Default values of variables in SCUAF

FILE NAME: B:FILENAME.SCU

Physical Environment

CLIMATE (CODES):
1. Lowland humid (default)
2. Lowland subhumid
3. Lowland semi-arid
4. Highland humid
5. Highland subhumid
6. Highland semi-arid

SOIL: Medium textured
SLOPE: Gentle

Agroforestry System

If spatial (default):
FRACTION OF LAND COVERED BY TREE: 0.4
FRACTION OF LAND COVERED BY CROP: 0.6

If rotational:
YEARS UNDER TREE: 3
YEARS UNDER CROP: 3
STARTING WITH: Crop

Soil Conditions

SOIL DEPTH CONSIDERED FOR CARBON (cm): 20

For soil medium-textured:

	Climate					
	1	2	3	4	5	6
INITIAL SOIL CARBON (kg/ha)	30000	15000	8000	45000	22000	11000
INITIAL TOPSOIL CARBON (fraction)	0.020	0.010	0.005	0.030	0.015	0.0075

Soil sandy: multiply above by 0.5
Soil clayey: multiply above by 1.25

TOTAL SOIL DEPTH (cm): 200

Table 1 (continued).

Erosion

	Climate 1	2	3	4	5	6
RAINFALL FACTOR (R):	1000	500	200	800	400	150
TREE COVER FACTOR (Ct):	0.006	0.01	0.1	0.006	0.01	0.1
CROP COVER FACTOR (Cc):	0.4	0.6	0.8	0.4	0.6	0.8

	Soil: Medium textured	Sandy	Clayey
SOIL ERODIBILITY FACTOR (K):	0.3	0.2	0.1

	Slope: Flat	Gentle	Moderate	Steep
SLOPE FACTOR (S):	0.15	0.35	3.5	11.0

TREE PROPORTIONALITY FACTOR: 0.8
CARBON ENRICHMENT FACTOR: 2.0

Plant Growth

NET PRIMARY PRODUCTION (kg DM/ha/yr, above-ground):

	Climate 1	2	3	4	5	6
TREE	20000	10000	5000	14000	8000	4000

CROP (ALL CLIMATES): 9000
APPORTIONMENT TO PLANT PARTS (fraction):

	LEAF	FRUIT	WOOD
TREE	0.32	0.02	0.66
CROP	0.67	0.33	0.00

ROOTS AS A FRACTION OF ABOVE-GROUND NPP: TREE: 0.4
CROP: 0.4

CARBON (AS FRACTION OF BIOMASS), TREE: 0.5
CARBON (AS FRACTION OF BIOMASS), CROP: 0.5

CARBON FRACTION RETAINED (GROWTH) ANNUALLY

PART	TREE	CROP
Leaf	0	0
Fruit	0	0
Wood	1.0	0
Root	0.67	0

CARBON FRACTION RETAINED (GROWTH) AT CUTYEAR

PART	TREE	CROP
Leaf	0	0
Fruit	0	0
Wood	0	0
Root	0	0

	TREE	CROP
FRACTION OF ROOTS BELOW SOIL DEPTH CONSIDERED:	0.6	0.4
CARBON/GROWTH FEEDBACK FACTOR:	0.5	1.0
DEPTH/GROWTH FEEDBACK FACTOR:	0.5	1.0

Table 1. (continued)

Removals

PERIOD AFTER WHICH THE TREE IS CUT (years) = 5

FRACTIONS REMOVED ANNUALLY

PART	TREE	CROP
Leaf	0	0
Fruit	0	1.0
Wood	0	0
Root	0	0

ADDITIONAL FRACTIONS REMOVED AT CUTYEAR

PART	TREE	CROP
Leaf	0	0
Fruit	0	0
Wood	1.0	0
Root	0	0

Additions

ORGANIC ADDITIONS TO TREE (kg/ha/yr): 0
ORGANIC ADDITIONS TO CROP (kg/ha/yr): 0
CARBON AS FRACTION OF ORGANIC ADDITIONS: 0.5

Assumptions about soil/plant processes

LOSS FROM ABOVE-GROUND PARTS IN CONVERSION TO HUMUS: 0.85
LOSS FROM ROOTS IN CONVERSION TO HUMUS: 0.67
LOSS FROM ORGANIC ADDITIONS IN CONVERSION TO HUMUS: 0.67
NUMBER OF HUMUS FRACTIONS CONSIDERED: One Fraction
MEDIUM-DECAY HUMUS:
K UNDER TREE: 0.030
K UNDER CROP: 0.040

Two-fraction assumption (not default):

SLOW-DECAY HUMUS:
K UNDER TREE: 0.010
K UNDER CROP: 0.750
PROPORTION OF INITIAL CARBON IN SLOW-DECAY FORM: 0.75
FRACTION OF PLANT PARTS BECOMING MEDIUM-DECAY HUMUS:

PART	FRACTION
Leaf	1.0
Fruit	1.0
Wood	1.0
Root	1.0
Org. Ads	1.0

FRACTION OF MEDIUM HUMUS TRANSFORMED ANNUALLY TO SLOW = 0.01

3 INPUTS AND OUTPUTS

3.1 The menu

This section gives an overview of the input, output and utility procedures of the model. Further details are given in the user's guide (Section 6).

All input and output utility operations commence from, and return to, the menu. Each set of inputs can be entered independently, to review or make changes, without affecting other data. Similarly, the output operations function independently. This allows a change to be made in one or a few variables, and the effects studied.

Thus from the user's point of view, the menu is a focal point, from which a choice of any operation can be made, returning after it is completed (Figure 3).

3.2 Inputs

Viewed in broad terms, there are three kinds of input to the SCUAF model:

- the physical environment;
- the land use system;
- plant-soil processes.

In addition, there is a short input of documentation to identify runs of the model (including assumptions made).

Inputs related to the physical environment consist of:

- Environment: broad classes of climate, soil texture and slope. These are not intended as a full record of environmental conditions, but are employed in the setting of default values.

- Initial soil conditions: specifically, values for total soil carbon and topsoil carbon percentage are called for. The user is also asked to select what depth of soil profile is to be treated in modelling.

- Soil erosion: the causative factors of erosion are entered, together with measured rates if available.

Inputs related to the land use system (normally agroforestry) consist of:

- Land use system: the spatial or temporal structure. If a spatial system, the proportion of ground cover under tree and crop components; if a rotational system, the number of years under tree and crop, and which comes first.

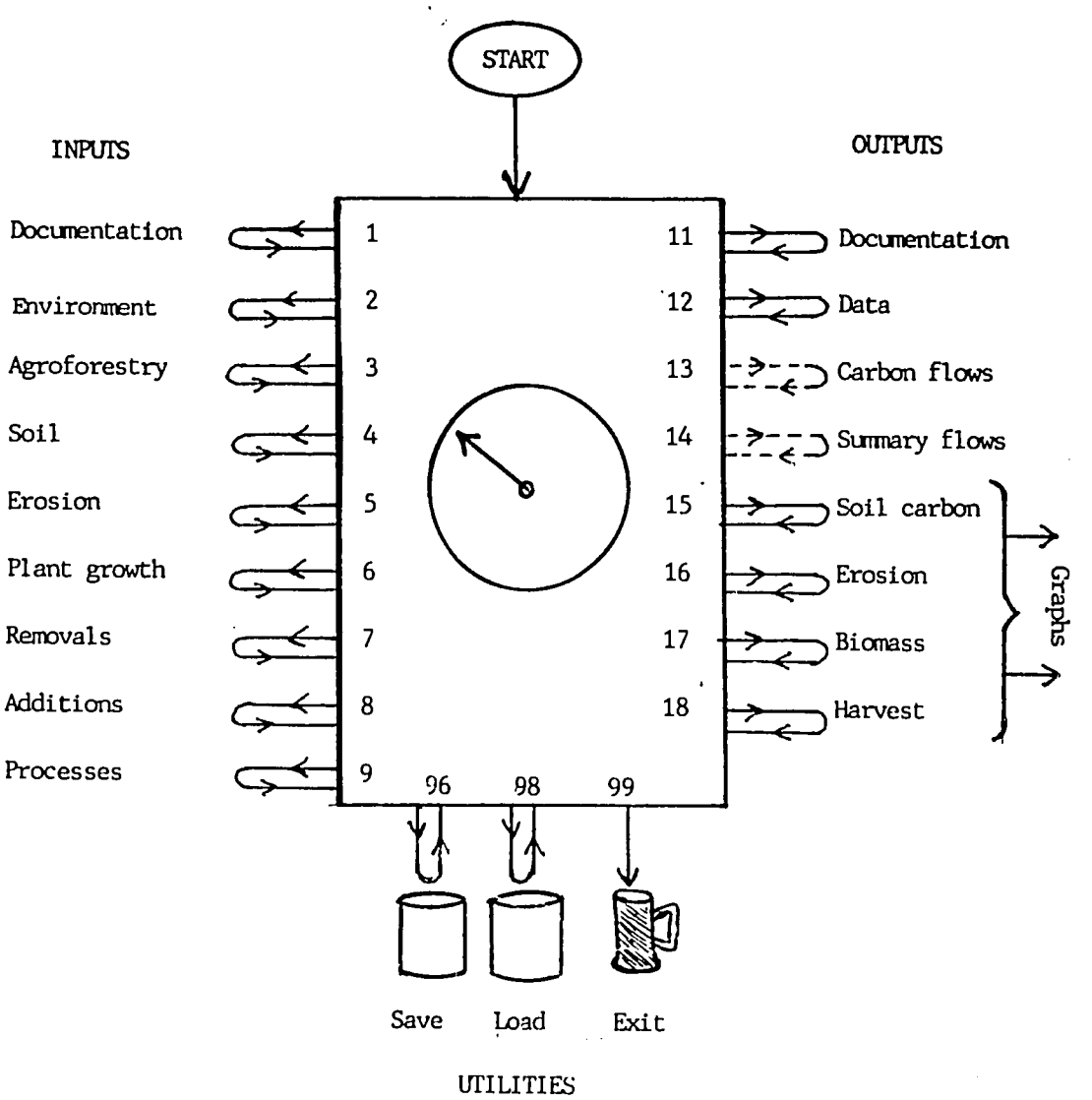


Figure 3. User's view of the SCUAF menu.

- Additions to the system if any: farmyard manure, compost, or mulch of external origin.

- Removals from the system: primarily, what parts of the plant components are harvested---crop fruit (grain, etc.), crop leaf (removal of residues), tree fruit, tree leaf (for fodder) and tree wood. Any other removals, e.g. loss in burning, or direct browsing by livestock, are for convenience included with harvest. This is also where the cutyear is input.

The input of soil processes covers first, losses on conversion of litter to humus, and secondly, oxidation losses from humus. The user also chooses whether to run the model on a one- or two-fraction humus assumption.

Subdivided in the above way, there are nine sets of inputs, which appear as numbered choices on the menu of the program. Each can be used either for initial input or for modification of an existing value.

As a matter of design, changes in the value of any one set of inputs has no effect on any other set. The input menu is as follows:

INPUT/MODIFY:
1. Documentation
2. Environment
3. Land use system
4. Soil conditions
5. Erosion
6. Plant growth
7. Removals
8. Additions
9. Soil processes

3.3 Outputs

There are three kinds of output:

- record of input conditions;
- internal flows within the model;
- changes with time in the soil/plant system:
  - as tables;
  - as graphs.

Each output can be on the screen or line printer. Examples of outputs are shown in Table 2 and Figure 4.

The output of the record of input conditions consists of:

- Documentation. A printing of the documentation as input. This can be used as a heading to any of the other outputs, to identify to which run of the model they refer.

- Variable settings. A full record of the inputs, including assumptions, in a particular run of the model.

The internal flows within the model were initially intended as a de-bugging device in development, but have been retained. They can be employed by the user who wants to see "what is going on inside" in any specified year, i.e. the flows between one carbon store and another. All flows are in terms of, kg carbon/ha/yr. There are two such outputs:

- Detailed flows: flows of each plant part, e.g. tree leaf, living-to-litter (= leaf fall during the year); crop fruit, living-to-harvest; tree wood, living-to-growth (= accumulated growth during the year); crop root, litter-to-humus (= the carbon from the crop root that is not lost in conversion and becomes soil humus).

- Summarized flows: as above, but without division into plants and parts, e.g. living-to-litter, litter-to-humus.

The changes with time in the soil/plant system are the basic outputs of the model. There are four such outputs, each of which consists of values over a period chosen by the user, e.g. 20 years:

- Changes in soil carbon. The total carbon present as soil humus; its changes during the preceding year (additions from plant decay, losses from erosion and oxidation); and, in the two-fraction assumption, its division between medium- and slow-decay humus.

- Changes in soil erosion. Values of the factors of soil erosion----R and S (constant), K and C (variable); erosion of total soil and of carbon; and soil depth.

- Changes in plant biomass production, as affected by soil. The consequences of the changed soil conditions, via the feedback factors (Section 2.6), on rates of plant growth. Whereas net primary production has been input per unit of tree or crop respectively, the output is in terms of biomass production per unit of the agroforestry system as whole; it thus reflects the proportional areas, or time periods, covered, and includes root production. It is important to note that this output only reflects such specified feedback effects; in practice, many other factors will affect plant growth.

- Changes in harvest. This is a selection from the biomass production of those plant parts which it has been stated will be harvested, showing the productive outputs from the land use system.

The output menu is as follows:

OUTPUT : 11. Documentation
12. Variable settings
13. Detailed carbon flows
14. Summarized carbon flows
15. Changes in soil carbon
16. Changes in soil erosion
17. Changes in plant biomass production (as affected by soil)
18. Changes in harvest

3.4 Saving and loading runs of the model

Once a set of data and assumptions has been entered, it can be saved, on a data diskette, for future use. It is identified by a filename.

This stored data can be subsequently loaded, from diskette to memory, to become the current model.

Thus the further options on the menu are:

96. Save the current model to disc file
98. Load a new model from disc file
99. Exit

3.5 Graphical output

The initial outputs are in tabular form. At the same time as being output to the screen or printer, they are stored on disk as spreadsheets. There is one spreadsheet to each kind of output: carbon, erosion, biomass and harvest.

These outputs can be converted into graphical form by means of the user's own graphical package. In ICRAF, the Lotus 1-2-3 package is employed.

Table 2. Specimen outputs from SCUAF. Documentation, and record of input data (first part).

DOCUMENTATION

FILE NAME: B:DEMOSP01.SCU
TITLE: DEMONSTRATION, SPATIAL SYSTEM
SOURCE: MAINLY DEFAULT DATA
COUNTRY:
LOCATION:
NOTES: LOWLAND SUBHUMID, GENTLE SLOPE, 25% TREE, 75% CROP, CROP NPP 6000 I
ASSUMPTIONS FOR OUTPUT: DEFAULT DATA EXCEPT AS ABOVE, AND TREE PRUNED ANNU
DATE OF INPUT: 23.2.87
DATE OF OUTPUT: 12.3.87

Physical Environment

CLIMATE=	Lowland Subhumi
SOIL=	Medium texturec
SLOPE=	Gentle

Agroforestry System

AGROFORESTRY SYSTEM=	Spatial
FRACTION OF LAND COVERED BY TREE=	0.25
FRACTION OF LAND COVERED BY CROP=	0.75

Soil Conditions

SOIL DEPTH CONSIDERED FOR CARBON (cm)=	20.
INITIAL SOIL CARBON (kg/ha)=	15000.
INITIAL CARBON FRACTION IN TOPSOIL=	0.010
TOTAL SOIL DEPTH (cm)=	200.

Erosion

RAINFALL FACTOR=	500.
ERODIBILITY FACTOR=	0.30
SLOPE FACTOR=	0.35
TREE COVER FACTOR=	0.010
CROP COVER FACTOR=	0.600
SOIL EROSION UNDER TREE=	525.
SOIL EROSION UNDER CROP=	31500
TREE PROPORTIONALITY FACTOR=	0.80
SOIL EROSION=	5171.
CARBON ENRICHMENT FACTOR=	2.00

Plant Growth

TREE, NET PRIMARY PRODUCTION=	10000.
CROP, NET PRIMARY PRODUCTION=	6000.

NPP OF PLANT PARTS

PART	TREE	CROP
Leaf	3200.	4000.
Fruit	200.	2000.
Wood	6600.	0.
Root	4000.	2400.

Table 2. (continued). Record of input data (second part).

CARBON (AS FRACTION OF BIOMASS), TREE=	0.50
CARBON (AS FRACTION OF BIOMASS), CROP=	0.50

CARBON FRACTION RETAINED (GROWTH) ANNUALLY

PART	TREE	CROP
Leaf	0.00	0.00
Fruit	0.00	0.00
Wood	1.00	0.00
Root	0.67	0.00

CARBON FRACTION RETAINED (GROWTH) AT CUTYEAR

PART	TREE	CROP
Leaf	0.00	0.00
Fruit	0.00	0.00
Wood	0.00	0.00
Root	0.00	0.00

FRACTION OF ROOTS TO BELOW SOIL DEPTH CONSIDERED

PART	TREE	CROP
Root	0.60	0.40

	TREE	CROP
CARBON/GROWTH FEEDBACK FACTORS=	0.50	1.00
DEPTH/GROWTH FEEDBACK FACTORS=	0.50	1.00

Additions

ORGANIC ADDITIONS TO TREE (kg/ha/yr)=	0.0
ORGANIC ADDITIONS TO CROP (kg/ha/yr)=	0.0
CARBON AS FRACTION OF ORGANIC ADDITIONS=	0.50

Removals

PERIOD AFTER WHICH THE TREE IS CUT (years)=	1

FRACTIONS REMOVED ANNUALLY

PART	TREE	CROP
Leaf	0.00	0.00
Fruit	0.00	1.00
Wood	0.00	0.00
Root	0.00	0.00

ADDITIONAL FRACTIONS REMOVED AT CUTYEAR

PART	TREE	CROP
Leaf	0.00	0.00
Fruit	0.00	0.00
Wood	1.00	0.00
Root	0.00	0.00

Assumptions about soil/plant processes

LOSS FROM ABOVE-GROUND PARTS IN CONVERSION TO HUMUS=	0.85
LOSS FROM ROOTS IN CONVERSION TO HUMUS=	0.67
LOSS FROM ORGANIC ADDITIONS IN CONVERSION TO HUMUS=	0.67
NUMBER OF HUMUS FRACTIONS CONSIDERED=	One Fraction
MEDIUM-DECAY HUMUS:	
K UNDER TREE=	0.030
K UNDER CROP=	0.040

Table 2. (continued). Outputs: changes in soil carbon;
changes in erosion. Cf Figure 4A and B.

C H A N G E S I N S O I L C A R B O N C O N T E N T

TIME	CARBON	OXIDATION	EROSION	ADDITION
0	15000.			
1	14867.	562.	103.	533.
2	14735.	558.	104.	529.
3	14603.	553.	104.	525.
4	14472.	548.	104.	520.
5	14341.	543.	104.	516.
6	14211.	538.	104.	512.
7	14082.	533.	104.	508.
8	13953.	528.	104.	504.
9	13825.	523.	104.	500.
10	13698.	518.	104.	496.
11	13571.	514.	104.	492.
12	13445.	509.	105.	488.
13	13320.	504.	105.	484.
14	13196.	500.	104.	480.
15	13072.	495.	104.	476.
16	12949.	490.	104.	472.
17	12827.	486.	104.	468.
18	12705.	481.	104.	464.
19	12585.	476.	104.	460.
20	12465.	472.	104.	456.

C H A N G E S I N E R O S I O N

T.	CLIMATE FACTOR	EROD FACTOR	SLOPE FACTOR	TREE COVER	CROP COVER	SOIL EROSION	CARBON EROSION	SOIL DEPTH
1	500.	0.30	0.35	0.010	0.60	5171.	103.	200.
2	500.	0.30	0.35	0.010	0.61	5227.	104.	200.
3	500.	0.30	0.35	0.010	0.61	5282.	104.	200.
4	500.	0.30	0.35	0.010	0.62	5337.	104.	200.
5	500.	0.30	0.35	0.010	0.62	5392.	104.	200.
6	500.	0.30	0.35	0.010	0.63	5447.	104.	200.
7	500.	0.30	0.35	0.010	0.63	5502.	104.	200.
8	500.	0.30	0.35	0.010	0.64	5557.	104.	200.
9	500.	0.30	0.35	0.010	0.64	5612.	104.	200.
10	500.	0.31	0.35	0.010	0.65	5666.	104.	200.
11	500.	0.31	0.35	0.010	0.65	5721.	104.	200.
12	500.	0.31	0.35	0.010	0.66	5775.	105.	200.
13	500.	0.31	0.35	0.011	0.66	5830.	105.	200.
14	500.	0.31	0.35	0.011	0.67	5884.	104.	199.
15	500.	0.31	0.35	0.011	0.67	5938.	104.	199.
16	500.	0.31	0.35	0.011	0.68	5991.	104.	199.
17	500.	0.31	0.35	0.011	0.68	6045.	104.	199.
18	500.	0.31	0.35	0.011	0.69	6098.	104.	199.
19	500.	0.31	0.35	0.011	0.69	6152.	104.	199.
20	500.	0.31	0.35	0.011	0.70	6205.	104.	199.

Table 2. (continued). Outputs: changes in plant biomass production as affected by soil; changes in harvest. Cf. Figure 4C and D.

C H A N G E S I N P L A N T B I O M A S S P R O D U C T I O N
(as affected by soil)

	TREE					CROP					
T	LEAF	FRUIT	WOOD	ROOT	TOTAL	LEAF	FRUIT	WOOD	ROOT	TOTAL	C+T
1	800.	50.	1650.	1000.	3500.	3000.	1500.	0.	1800.	6300.	9800
2	796.	50.	1643.	995.	3484.	2973.	1486.	0.	1784.	6243.	9727
3	793.	50.	1635.	991.	3468.	2946.	1473.	0.	1768.	6186.	9655
4	789.	49.	1628.	987.	3453.	2919.	1460.	0.	1751.	6130.	9583
5	786.	49.	1620.	982.	3437.	2892.	1446.	0.	1735.	6074.	9511
6	782.	49.	1613.	978.	3422.	2866.	1433.	0.	1719.	6018.	9440
7	779.	49.	1606.	973.	3406.	2839.	1420.	0.	1704.	5962.	9368
8	775.	48.	1599.	969.	3391.	2813.	1406.	0.	1688.	5907.	9298
9	772.	48.	1591.	964.	3375.	2787.	1393.	0.	1672.	5852.	9227
10	768.	48.	1584.	960.	3360.	2761.	1380.	0.	1656.	5797.	9157
11	765.	48.	1577.	956.	3345.	2735.	1367.	0.	1641.	5743.	9088
12	761.	48.	1570.	951.	3330.	2709.	1354.	0.	1625.	5689.	9018
13	758.	47.	1563.	947.	3315.	2683.	1342.	0.	1610.	5635.	8950
14	754.	47.	1556.	943.	3300.	2658.	1329.	0.	1595.	5581.	8881
15	751.	47.	1549.	939.	3285.	2632.	1316.	0.	1579.	5528.	8813
16	748.	47.	1542.	934.	3271.	2607.	1304.	0.	1564.	5475.	8745
17	744.	47.	1535.	930.	3256.	2582.	1291.	0.	1549.	5422.	8678
18	741.	46.	1528.	926.	3241.	2557.	1279.	0.	1534.	5370.	8611
19	738.	46.	1521.	922.	3227.	2532.	1266.	0.	1519.	5318.	8545
20	734.	46.	1514.	918.	3212.	2508.	1254.	0.	1505.	5267.	8479.

C H A N G E S I N H A R V E S T

TIME	T.FRUIT	T.LEAF	T.WOOD	C.FRUIT	C.LEAF
1	0.	0.	1650.	1500.	0.
2	0.	0.	1643.	1486.	0.
3	0.	0.	1635.	1473.	0.
4	0.	0.	1628.	1459.	0.
5	0.	0.	1620.	1446.	0.
6	0.	0.	1613.	1433.	0.
7	0.	0.	1606.	1419.	0.
8	0.	0.	1599.	1406.	0.
9	0.	0.	1591.	1393.	0.
10	0.	0.	1584.	1380.	0.
11	0.	0.	1577.	1367.	0.
12	0.	0.	1570.	1354.	0.
13	0.	0.	1563.	1341.	0.
14	0.	0.	1556.	1329.	0.
15	0.	0.	1549.	1316.	0.
16	0.	0.	1542.	1303.	0.
17	0.	0.	1535.	1291.	0.
18	0.	0.	1528.	1278.	0.
19	0.	0.	1521.	1266.	0.
20	0.	0.	1514.	1254.	0.

Table 2. (continued). Outputs: changes in soil carbon, under the two-fraction humus assumption. Cf. Figure 4E.

DOCUMENTATION

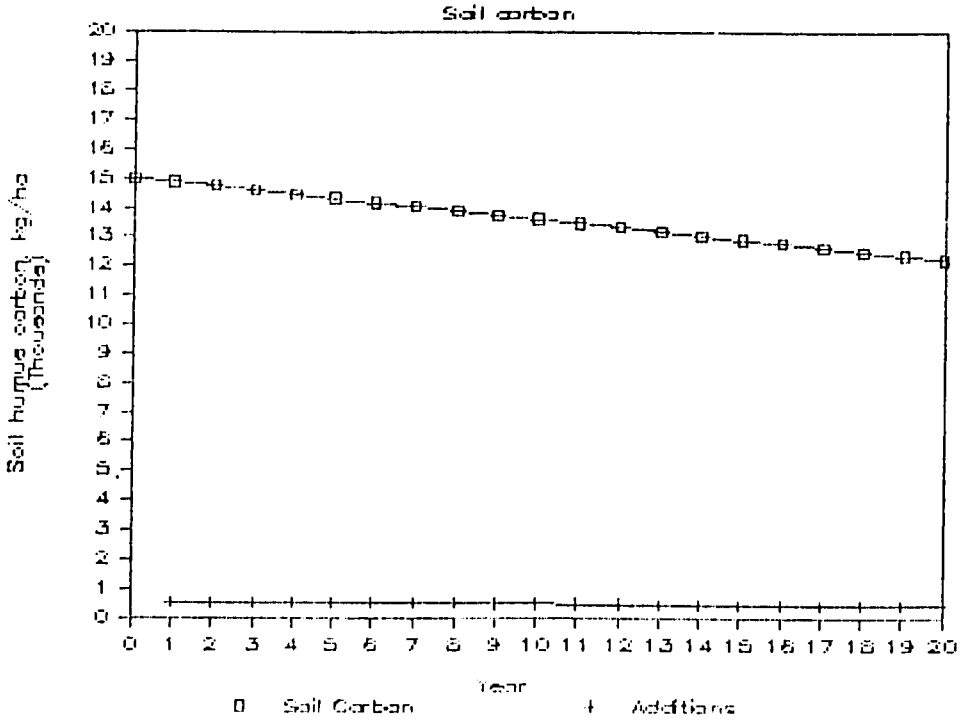
FILE NAME: B:DEMOSP02.SCU
TITLE: DEMONSTRATION, SPATIAL SYSTEM
SOURCE: MAINLY DEFAULT DATA
COUNTRY:
LOCATION:
NOTES: AS RUN 01, BUT INITIAL SOIL CARBON 30 000 KG/HA/YR
ASSUMPTIONS FOR OUTPUT: TWO HUMUS FRACTIONS
DATE OF INPUT: 23.2.87
DATE OF OUTPUT: 12.3.87

C H A N G E S I N S O I L C A R B O N C O N T E N T

TIME	MEDIUM	SLOW	TOTAL	MEDOXN	SLWOXN	EROSN	TRANS	ADDITN
0	7500.	22500.	30000.					
1	7573.	22350.	29923.	281.	225.	103.	75.	533.
2	7648.	22202.	29850.	284.	224.	103.	76.	537.
3	7723.	22057.	29780.	287.	222.	103.	76.	542.
4	7800.	21913.	29714.	290.	221.	103.	77.	547.
5	7879.	21772.	29651.	293.	219.	103.	78.	551.
6	7958.	21633.	29592.	295.	218.	102.	79.	556.
7	8039.	21497.	29536.	298.	216.	102.	80.	561.
8	8122.	21362.	29484.	301.	215.	102.	80.	566.
9	8206.	21230.	29435.	305.	214.	101.	81.	571.
10	8291.	21099.	29391.	308.	212.	101.	82.	576.
11	8379.	20971.	29350.	311.	211.	100.	83.	582.
12	8467.	20845.	29313.	314.	210.	100.	84.	587.
13	8558.	20722.	29280.	318.	208.	100.	85.	592.
14	8650.	20600.	29250.	321.	207.	99.	86.	598.
15	8745.	20480.	29225.	324.	206.	98.	87.	604.
16	8841.	20363.	29204.	328.	205.	98.	87.	609.
17	8939.	20248.	29187.	332.	204.	97.	88.	615.
18	9039.	20135.	29174.	335.	202.	97.	89.	621.
19	9141.	20024.	29165.	339.	201.	96.	90.	627.
20	9246.	19915.	29161.	343.	200.	95.	91.	634.

SPATIAL SYSTEM, 25% TREE, 75% CROP

A.



B.

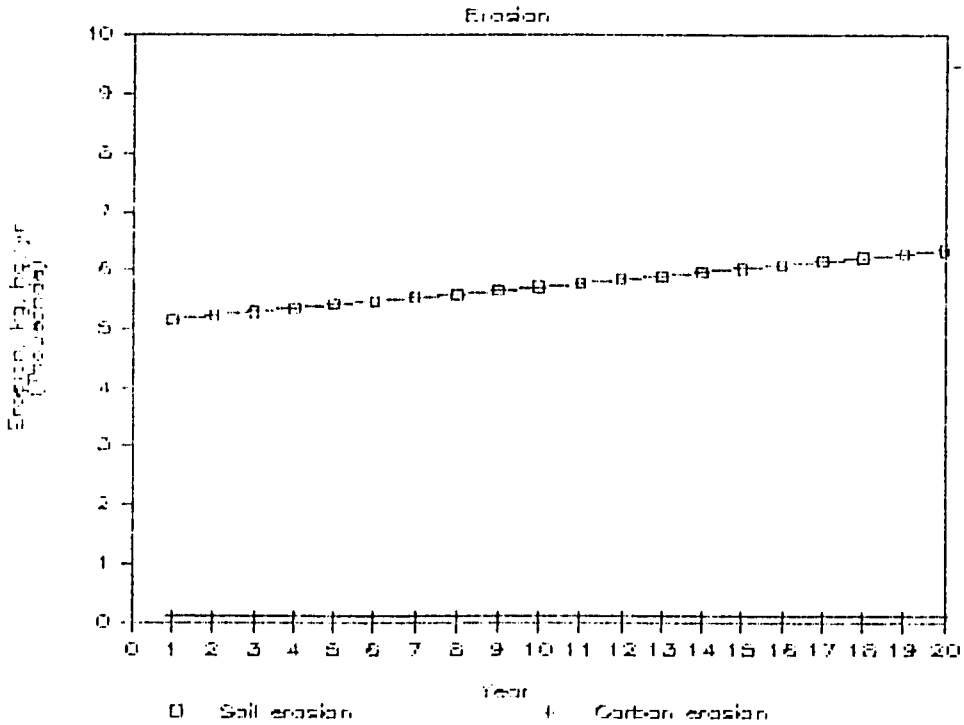
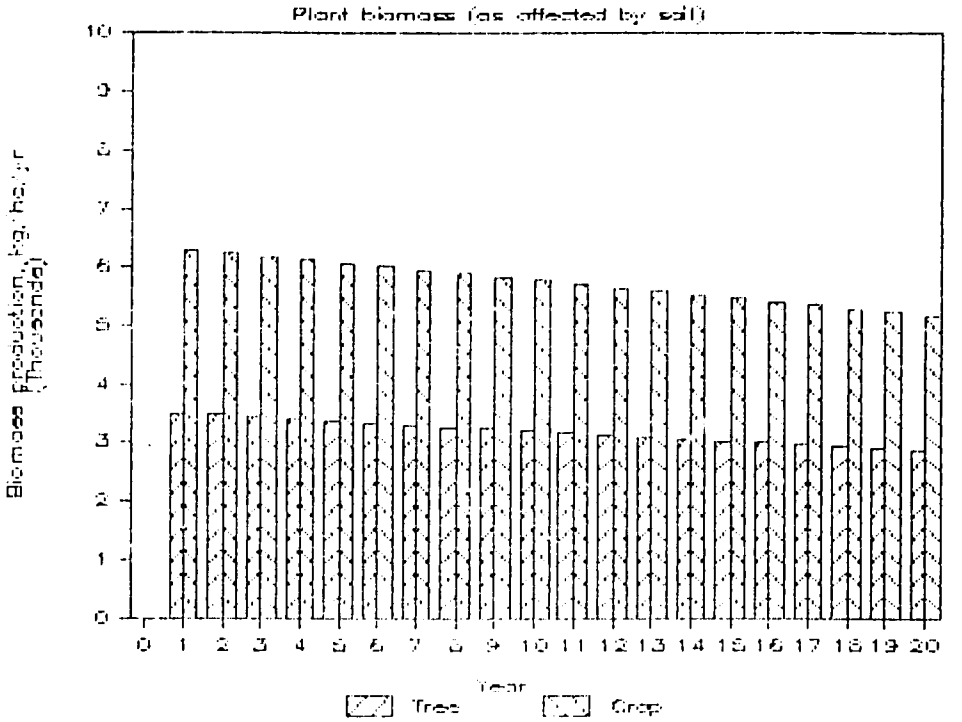


Figure 4. Specimen outputs from SCUAF.

A. Changes in soil carbon. B. Changes in erosion.

SPATIAL SYSTEM, 25% TREE, 75% CROP

C.



D.

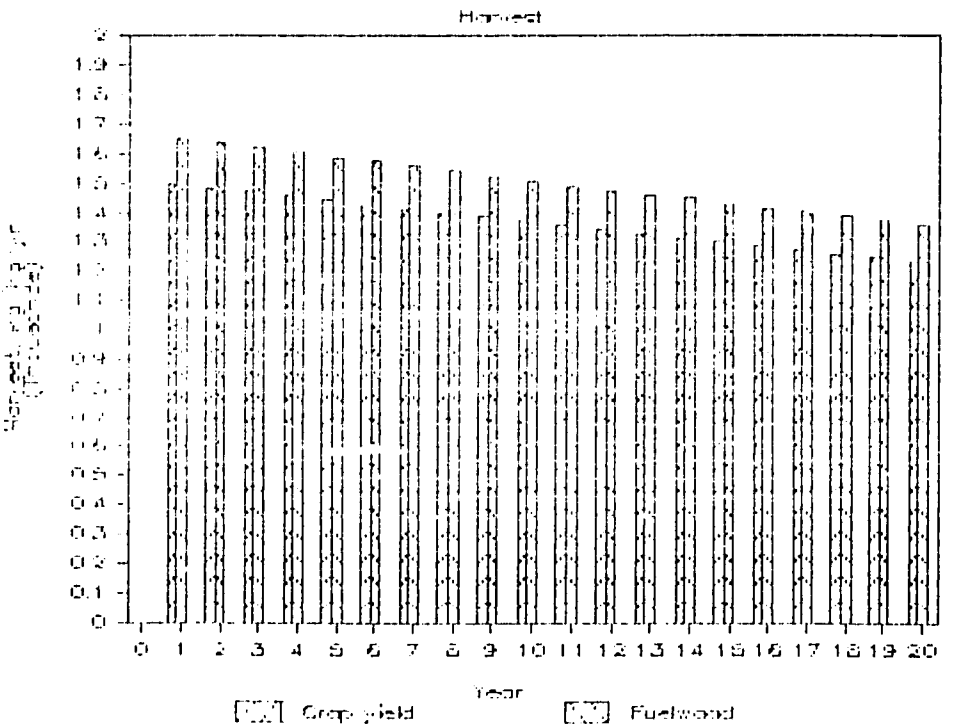


Figure 4. (continued). C. Changes in plant biomass production, as affected by soil.

D. Changes in harvest.

E.

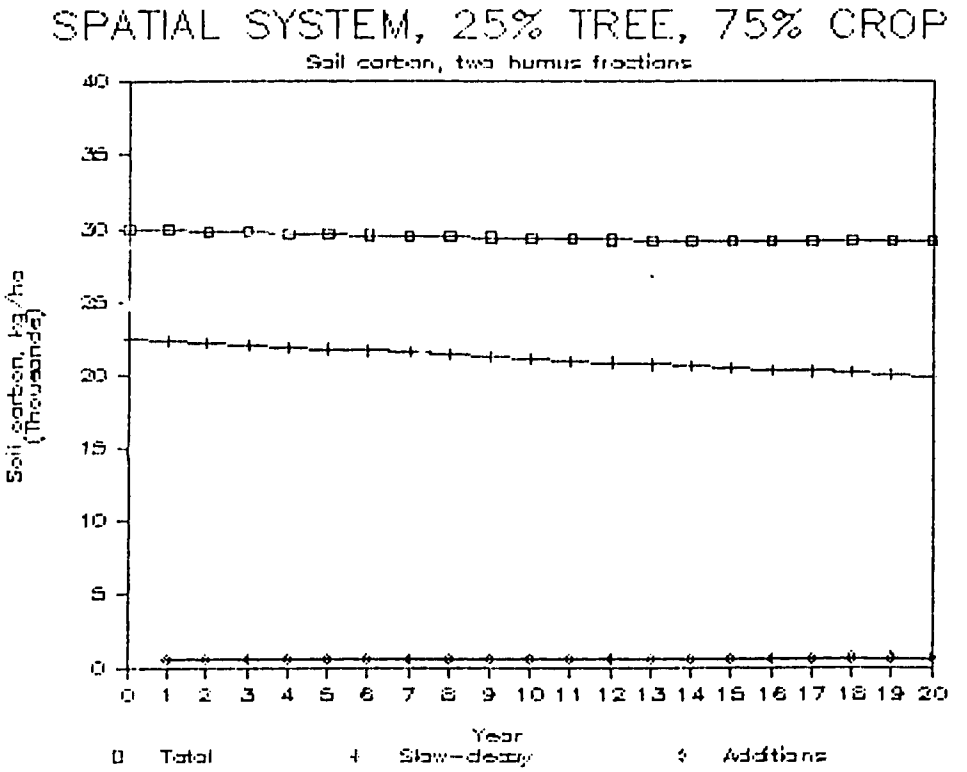


Figure 4. (continued). E. Changes in soil carbon, two-fraction humus assumption. As compared with the one-fraction assumption (Figure 4A), the relatively inert slow-decay humus exerts a stabilizing effect on total carbon.

4 TECHNICAL ASPECTS

4.1 Computer hardware and software

SCUAF runs on IBM-compatible microcomputers using the MS-DOS/PC-DOS operating system. Within ICRAF, it has been run on the Olivetti M24, Wang PC and IBM PC. It can be run either on twin disk drives, with the program in Drive A and a data disk in Drive B; or with the program loaded onto hard disk and a data disk in Drive B. A standard 80-column line printer is used for output.

The compiled executive program file, SCUAF.EXE, occupies 93 kB. To run the program requires a minimum of 256 kB of RAM memory.

Tabular output is stored on Drive B as four files: CARBON.PRN, EROSION.PRN, BIOMASS.PRN and HARVEST.PRN. These are pure ASCII files and can be imported into the user's package for graphical output; the extension .PRN has been added to make them importable to the Lotus 1-2-3 spreadsheet. In ICRAF, the Lotus-2 package is employed, the 1-2-3 option for screen graphical output and the Printgraph option for printing.

4.2 The SCUAF program

4.2.1 General

The first attempt to develop the program made use of Basic language. This became operative, for carbon changes only, and a few outputs were published (Young, 1986a). Three problems were encountered. First, the memory limit for a Basic program was substantially exceeded, necessitating the use of chaining. Secondly, the program was constructed in such a way that a complete set of inputs from the keyboard was required for every run, i.e. it was not possible to change the value of a single variable, retaining all other values, and rerun. Thirdly, the complexity of the operations was such that difficulties were encountered every time a modification to the program was made.

The program was therefore rewritten, using MS-Pascal language. The uncompiled program consists of two modules (input and output) which can be separately compiled and then linked to form the main executable program SCUAF. The input module includes a procedure that interfaces the user to all the input/output procedures. Figure 5 is a flow chart that shows how this is achieved.

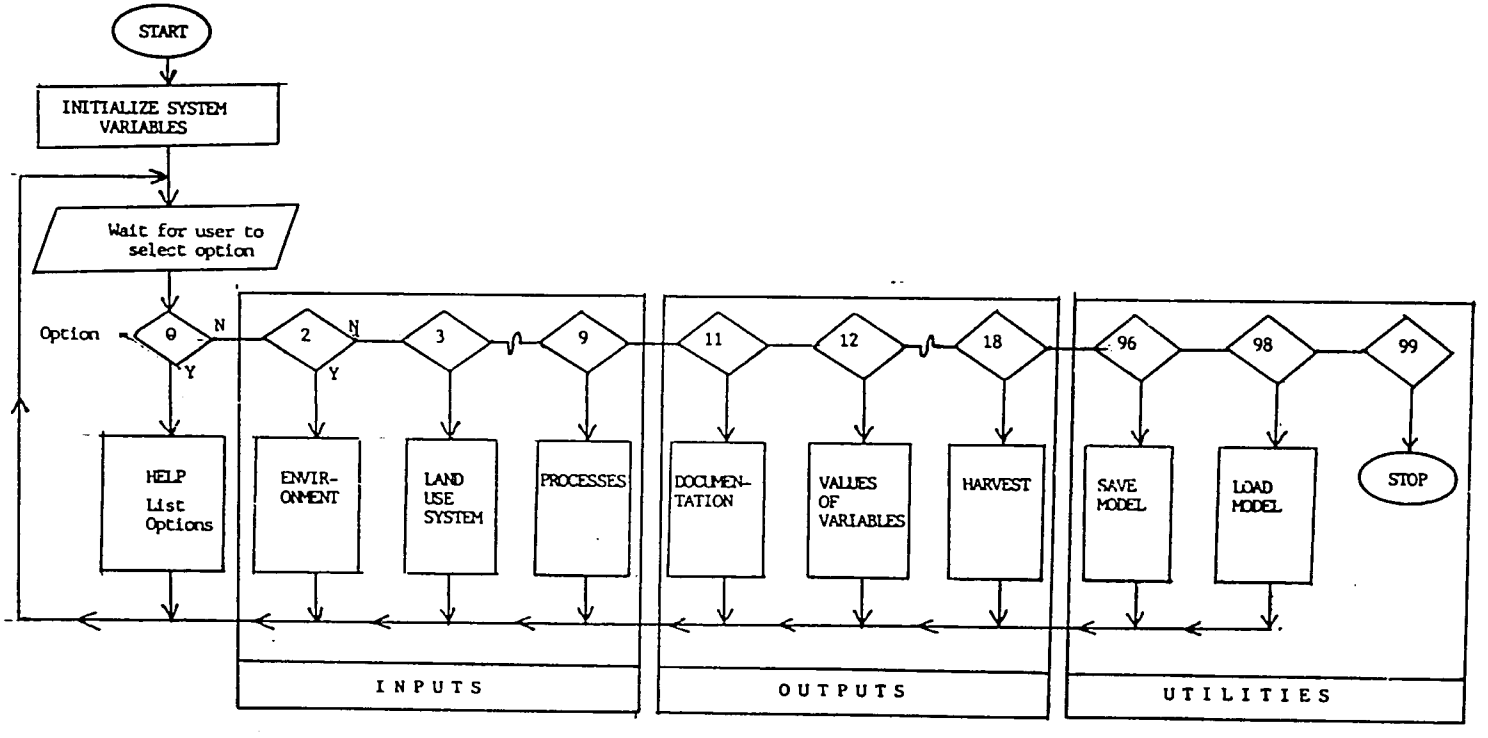


Figure 5. The user interface of SCUAF.

4.2.2 Initialization of system variables

It was required that there should be a system of default values (Section 2.7), some of which are dependent on other, previously set, values: specifically, many default values are dependent on the user's setting of classes of climate, soil and slope. All default values should be displayed during input, and the user given the opportunity to change them.

This was programmed by making those variables for which the default values were dependent upon climate, soil or slope into arrays, dependent upon coded values of the latter. For example, the value of initial soil carbon is a variable:

```
InitialCarbon:Array [ClimateIndex] of Real
```

where ClimateIndex may have values of 1 to 6. The initialization of InitialCarbon is then dependent on the index value, for example,

```
InitialCarbon [1] := 30000;
InitialCarbon [2] := 15000;
```

these being the default values of initial soil carbon for climates [1], lowland humid, and [2], lowland subhumid, respectively.

After the initialization of the system variables, the user is allowed to select any of the input/output utility options avaiable in SCUAF. The list of options is displayed when the option 0 (= HELP) is selected.

This requirement is met by making the program menu-driven. Each menu item operates individually, without affecting others. The user may select one set of inputs, change one or more variables within it, and rerun the outputs. The menu is shown from the user's viewpoint in Figure 3 (p. 24); the technical manner of achieving this is as shown in Figure 5.

4.2.3 Inputs

While Figure 5 illustrates the program flow during user input/output operation, it does not bring out the main features important to the program development. Figure 6 is a representation of the model's main components and the flows of carbon between them.

Each circle in Figure 6 is referred to as a node; they represent carbon sources and/or sinks. For instance, during photosynthesis, carbon may be said to flow from the atmosphere to the living plant. The flow is represented as the arrow between the two nodes, Atmosphere and Livingplant. Two types of flows can be identified, those that constitute: (i) the plant compartment and (ii) the soils compartment.

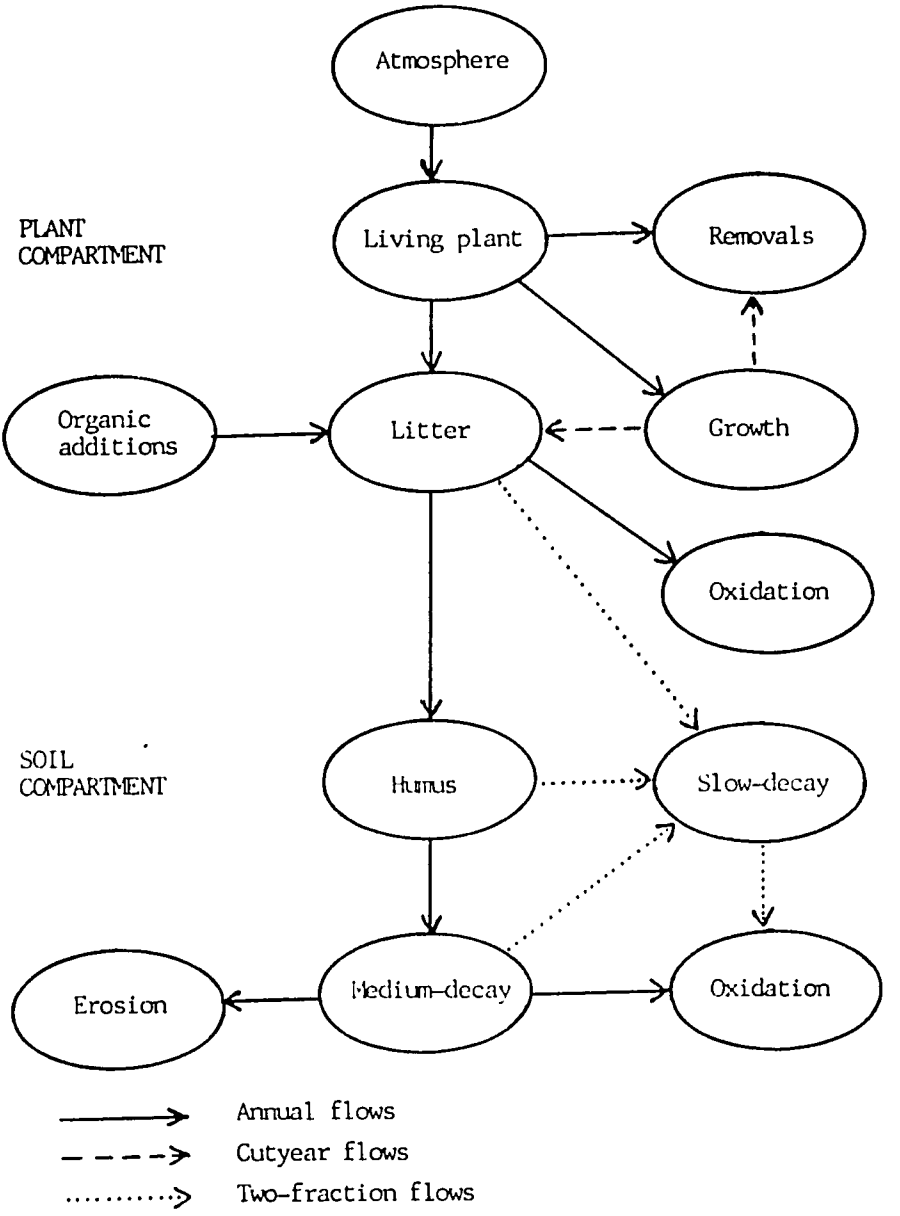


Figure 6. Carbon flows in SCUAF

i. The plant compartment In the plant compartment there are two plants, TREE and CROP, each consisting of four parts, LEAF, FRUIT, WOOD and ROOT, giving eight plant parts: TREE-LEAF, TREE-FRUIT,.....CROP-ROOT. It was required that the user must be able to direct the flows, or movements of dry matter and carbon, in each of these plant parts individually.

RATE is a SCUAF function which returns the amount of carbon that flows between any two nodes in the plant compartment. It has the following arguments:

Source - the node from which carbon originates
Sink - the node which carbon flow is required
Plant - the type of plant for which the node is needed, i.e tree or crop
Part - the part of the plant for between which the flow is required, i.e leaf, fruit, wood or root.

In programming the function RATE, it was required that some of the flows shown may not be annual. Those marked with broken lines occur only in a cutyear, a year in which the tree is managed differently (e.g coppicing and fuelwood harvest).

ii. The soil compartment The main difference between the flows in the plant and soil compartments is that in the latter, flows are not broken down to the plant/part level. Thus the flows shown in Figure 6 are total carbon transfers between the nodes.

For each flow, all the information that SCUAF needs from the user is supplied during the input phase. The flow chart given in Figure 5 shows how the user accesses all the nodes in Figure 6 to input the necessary data.

The flows shown in Figure 6 are instantaneous, i.e. the function RATE calculates the flows between the nodes at a particular instant in time. The output procedure then uses RATE to compute the system state at different times (years).

4.2.4 Outputs

The outputs are generated by a procedure SIMULATE which is cyclic in operation and is the focus of the output operations. It contains local variables representing those values which change with time, such as soil carbon, erosion and plant growth. The procedure puts current values into these variables at year t-1, calculates processes during year t (including calling upon the plant compartment for flows from litter to humus), then calculates the new state of the system at the end of year t.

This state is necessarily calculated for the full set of conditions in the model --- soil carbon, erosion and plant growth; a procedure DISPLAYOUTPUT then chooses which output option has been selected by the user, and prints it. The cycle is then repeated for the succeeding year.

Thus, the output values are not stored as arrays of years, e.g. soil carbon in years 1,2,3,..... Instead, calculation and output proceed alternately, year by year.

In general terms the programming is done as follows (Figure 7). Let St be the system state, i.e. the state of the soil, erosion and plant growth, at a time t, and let S_{t-1} represent the state of the same system one year before.

If So represents the system state at time θ, i.e. the beginning of the simulation, then the system state at any time may be expressed as:

$$S = \begin{cases} f\ (S_0) & \text{for } t = \theta \\ f\ (S_{t-1}) & \text{for } t > 0 \end{cases}$$

where f is a function that refers the current state, using the previous state as one of the arguments. This function also takes care of feedbacks. S_0 is computed from default settings of system variables and/or new values that the user may have supplied in the input phase.

Now let t_i be the initial time that the user wishes to observe St (usually, but not necessarily, θ), and let t_f be the final time for which he wishes to produce results.

The programming is done in such a way that computation always starts at $t = \theta$, but the display commences after $t = t_i$, and halts when $t = t_f$. The flow chart in Figure 7 shows the main components of the procedure SIMULATE.

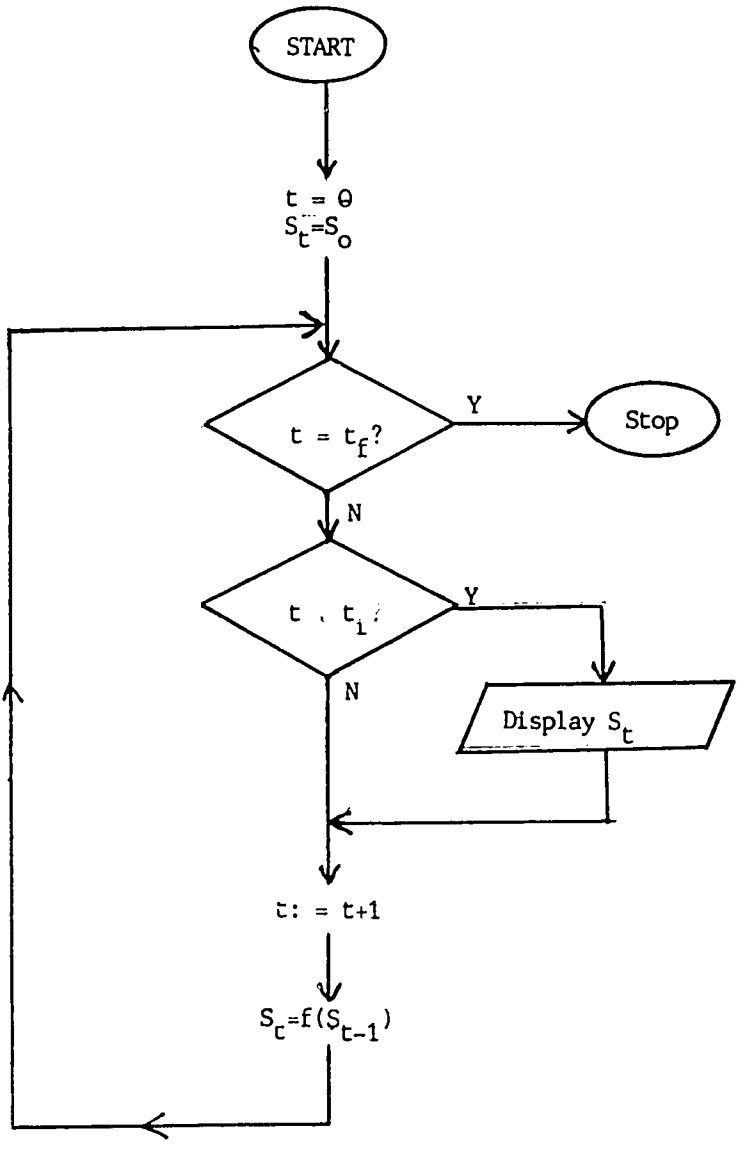


Figure 7. Outline of procedure SIMULATE for calculating annual changes

5 EXAMPLES AND APPLICATIONS

5.1 Introduction

During development, the SCUAF model was applied to some 30 sets of data derived from publications, including studies based on natural vegetation, plantation forestry, agriculture and agroforestry. Non-agroforestry systems were included with the aim of calibrating the model by simulating observed data. Some results from these studies have been presented elsewhere (Cheatle et al., in press).

To illustrate how the model is applied, two examples are given here, one for each of the main classes of agrosylvicultural systems: spatial and rotational. Spatial systems are those in which the tree and crop components each occupy part of their land area, rotational systems those in which they alternate in time. In spatial mixed systems, the trees and crops are intimately mixed over more or less the whole area. In spatial zoned systems, the tree component is planted according to some regular arrangement, e.g. blocks or rows, or is confined to some specific part of the area, e.g. field boundaries. Examples of spatial zoned and rotational systems are given here. For one of the more comprehensive data sources on a spatial mixed system, the study of coffee and cocoa under shade trees in Venezuela by Aranguren et al. (1982) is suggested.

5.2 Data availability

It was found that when working from publications as sources, the data given are almost always incomplete. In some cases, critical facts which appear self-evident to authors are omitted, for example, whether crop residues were retained or removed. Frequently, there are one or more important gaps in the data, without which a plant-soil carbon cycle cannot be constructed. The most common deficiencies are:

i. Lack of any attempt to determine root growth and turnover.

ii. Soil carbon is given as a percentage but without bulk density, thus requiring guesswork to estimate initial soil carbon.

iii. No measurements are made of soil erosion on, or in conjunction with, the experimental site.

iv. Either there is no monitoring of soil changes or, where this is found, statistical control appears to be absent.

Default values are used to fill in such gaps in data.

One of the objectives of the SCUAF model is to avoid critical data deficiencies in future agroforestry experimental work by setting out the range of data required to construct a complete plant-soil carbon cycle.

5.3 A spatial zoned system: alley cropping

Alley cropping is the best-known spatial zoned agroforestry system (although not at present the most widely practised by farmers). The experiments at IITA, Ibadan, described in Kang et al. (1981, 1985), are classic studies and are so far unique in having monitored soil changes over six years.

Description The climate is lowland humid (close to the boundary with subhumid) with two rainy seasons, and the soil is sandy (FAO albic arenosol). *Leucaena leucocephala* (leuco) is planted in rows 4 m apart, intercropped with alternate maize and cowpea, one crop of both every year. The leuco is pruned at 5- to 6-week intervals during periods of crop growth; woody stems are removed, other plant matter is laid on the soil surface. Of three levels of fertilizer included in the experiment, the unfertilized plots are considered here.

On plots with leuco prunings returned to the soil, topsoil organic matter rose from 0.98% to 1.07% in seven years, 1976-1983. Maize and cowpea yields were maintained. On a control plot from which prunings were removed, topsoil carbon declined to 0.65% and crop yields became substantially lower.

Data and modelling Data are given on leuco leaf and wood production, maize and cowpea harvests and residues, plus a limited indication of leuco root production. From the published design, the system is modelled as 25% tree, 75% crop cover. Tree and crop growth data are given for the plots as a whole, and are therefore scaled up proportionately for the form of input used in the model. Crop yield is taken as the sum of average maize and cowpea yields. It is assumed that crop residues are retained. The slope assumed to be gentle. No data on erosion are given. Soil changes are modelled for the 0-15 cm layer. No bulk densities are given, but assuming these to be 1.0, then 0.98, 1.07 and 0.65% carbon correspond to 14 700, 16 050 and 9750 kg Carbon/ha respectively. Table 3 gives the input data for the case where leuco prunings are retained.

Results Figure 6 shows four runs of the model, Runs 1 and 2 for leuco leaf prunings retained on the soil, Runs 3 and 4 for control plots where they are removed, together with observed values of soil carbon. Run 1 uses a decomposition constant of 0.04, applied to the whole area on the assumption that the tree rows are narrow at ground level. After 6 years, soil carbon rises to nearly 18 000 kg/ha, appreciably above the observed value. The latter is correctly modelled in Run 2 by raising the decomposition constant to 0.06. The considerable loss of soil carbon where prunings are removed can only be simulated by higher values of the decomposition constant: 0.09 if crop residues are removed (Run 3) or 0.11 if they are retained (Run 4).

Table 3. Alley cropping, Ibadan, Nigeria. Record of input data.

DOCUMENTATION

FILE NAME: B:KANG8501.SCU
TITLE: IITA AC, LEUCO/MAIZE+COWPEA
SOURCE: KANG ET AL., 1981, 1985
COUNTRY: NIGERIA
LOCATION: IITA IBADAN
NOTES: PLOTS WITH LEUCO PRUNINGS RETAINED, NO FERTILIZER
ASSUMPTIONS FOR OUTPUT: DEFAULT EXCEPT FEEDBACKS=0, Kt=Kc=0.04
DATE OF INPUT: 19.1.87
DATE OF OUTPUT: 12.3.87

Physical Environment

CLIMATE=	Lowland Humid
SOIL=	Sandy
SLOPE=	Gentle

Agroforestry System

AGROFORESTRY SYSTEM=	Spatial
FRACTION OF LAND COVERED BY TREE=	0.25
FRACTION OF LAND COVERED BY CROP=	0.75

Soil Conditions

SOIL DEPTH CONSIDERED FOR CARBON (cm)=	15.
INITIAL SOIL CARBON (kg/ha)=	14700.
INITIAL CARBON FRACTION IN TOPSOIL=	0.010
TOTAL SOIL DEPTH (cm)=	200.

Erosion

RAINFALL FACTOR=	1000
ERODIBILITY FACTOR=	0.20
SLOPE FACTOR=	0.35
TREE COVER FACTOR=	0.006
CROP COVER FACTOR=	0.400
SOIL EROSION UNDER TREE=	420.
SOIL EROSION UNDER CROP=	28000
TREE PROPORTIONALITY FACTOR=	0.80
SOIL EROSION=	4557.
CARBON ENRICHMENT FACTOR=	2.00

Plant Growth

TREE, NET PRIMARY PRODUCTION=	41960.
CROP, NET PRIMARY PRODUCTION=	9508.

NPP OF PLANT PARTS

PART	TREE	CROP
Leaf	23400.	6364.
Fruit	0.	3141.
Wood	18560.	0.
Root	833.	3803.

Table 3. (continued)

CARBON (AS FRACTION OF BIOMASS), TREE=		0.50	
CARBON (AS FRACTION OF BIOMASS), CROP=		0.50	
CARBON FRACTION RETAINED (GROWTH) ANNUALLY			
.	PART	TREE	CROP
.	Leaf	0.00	0.00
.	Fruit	0.00	0.00
.	Wood	1.00	0.00
.	Root	0.00	0.00
CARBON FRACTION RETAINED (GROWTH) AT CUTYEAR			
.	PART	TREE	CROP
.	Leaf	0.00	0.00
.	Fruit	0.00	0.00
.	Wood	0.00	0.00
.	Root	0.00	0.00
FRACTION OF ROOTS TO BELOW SOIL DEPTH CONSIDERED			
.	PART	TREE	CROP
.	Root	0.60	0.40
.		TREE	CROP
CARBON/GROWTH FEEDBACK FACTORS=		0.00	0.00
DEPTH/GROWTH FEEDBACK FACTORS=		0.00	0.00

Additions

ORGANIC ADDITIONS TO TREE (kg/ha/yr)=	0.0
ORGANIC ADDITIONS TO CROP (kg/ha/yr)=	0.0
CARBON AS FRACTION OF ORGANIC ADDITIONS=	0.50

Removals

PERIOD AFTER WHICH THE TREE IS CUT (years)=		1	
FRACTIONS REMOVED ANNUALLY			
.	PART	TREE	CROP
.	Leaf	0.00	0.00
.	Fruit	0.00	1.00
.	Wood	1.00	0.00
.	Root	0.00	0.00
ADDITIONAL FRACTIONS REMOVED AT CUTYEAR			
.	PART	TREE	CROP
.	Leaf	0.00	0.00
.	Fruit	0.00	0.00
.	Wood	0.00	0.00
.	Root	0.00	0.00

Assumptions about soil/plant processes

LOSS FROM ABOVE-GROUND PARTS IN CONVERSION TO HUMUS=	0.85
LOSS FROM ROOTS IN CONVERSION TO HUMUS=	0.67
LOSS FROM ORGANIC ADDITIONS IN CONVERSION TO HUMUS=	0.67
NUMBER OF HUMUS FRACTIONS CONSIDERED=	One Fraction
MEDIUM-DECAY HUMUS:	
K UNDER TREE=	0.030
K UNDER CROP=	0.040

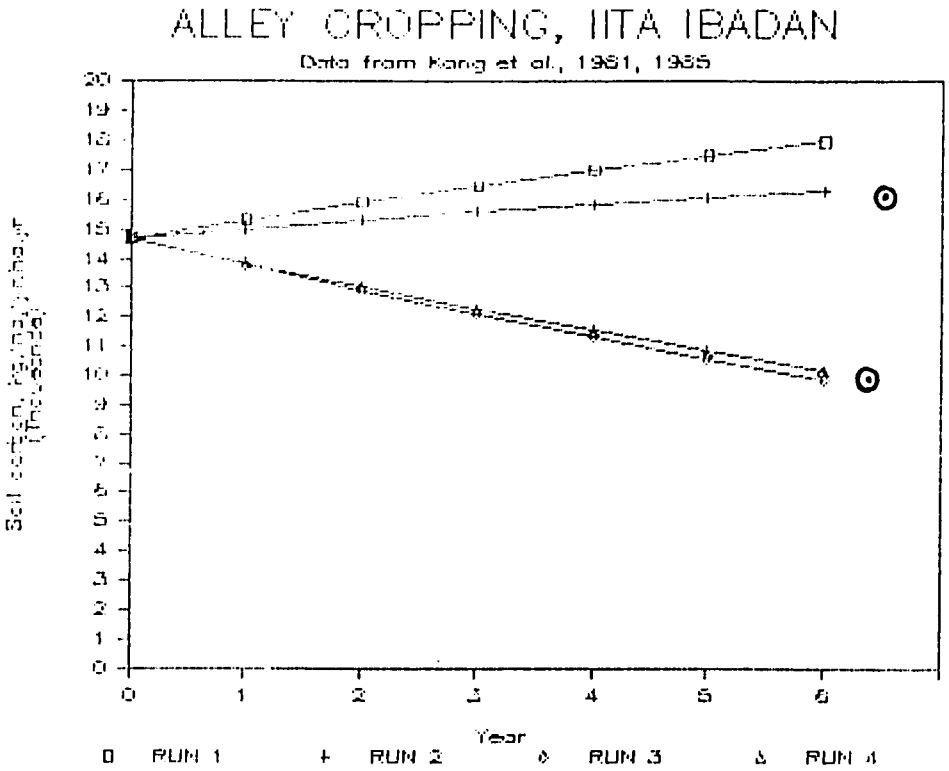


Figure 8. Alley cropping, Ibadan, Nigeria: Changes in soil carbon. The circles show observed soil carbon after 6 years. Runs 1 and 2, leuco prunings retained on soil. Runs 3 and 4 control plot with leuco prunings removed, showing rapid soil degradation. For assumptions of model runs, see text.

Discussion Dry matter production from leuco on this site is very high, 10 500 kg/yr per hectare of total land. This is equivalent to 42 000 kg/ha/yr per unit area of tree, about twice the value of typical natural forest, a situation partly explained by oblique light to the tree rows and frequent pruning. No statistical control of the soils data is given, but the rise from 0.98 to 1.07% carbon probably indicates no significant difference from a steady state, i.e. a sustainable system. The decline to two-thirds the value of initial carbon on the control plots without leuco residues indicates rapid soil degradation. The indications are that the decomposition constant for soil carbon on this site is at least 6% per year, or 50% above the commonly-assumed value of 4%; this is not unreasonable for a sandy, and thus well-aerated, soil with high temperatures and two rainy seasons. This situation makes the capacity of intercropped leuco to sustain soil fertility the more noteworthy.

5.4 A rotational system: shifting cultivation

The application of the model to a rotational land use system may be illustrated by an example of shifting cultivation from Mindanao, The Philippines (Kellman, 1969). First, the system is modelled with a long period of forest fallow, then the effects of shortening the fallow are simulated.

Description The climate is lowland humid, formerly under evergreen dipterocarp rain forest, now much replaced by various stages of secondary succession. Most land is steeply sloping. Soils are developed from andesite, have very low base saturation, relatively high topsoil organic matter (5-12%), probably either ferralsols or acrisols (FAO). There is some net loss of soil carbon during pre-cultivation burning, suggesting loss not only of virtually all litter but oxidation of some soil carbon also. At the time of the study, land shortage was not severe, and a rotation of 22-3 years cropping with some 15 years forest fallow was typical (R factor = 12%). Maize and upland rice are the main crops. The fallow succession is from herbaceous communities through fast-growing softwoods to hardwood forest. It is suggested that soil fertility is maintained with 15 or more years fallow, but that there may be progressive degradation if this is shortened.

Data and modelling The source gives data on soil conditions, erosion and litter production. The approach of space-time substitution was used, recording conditions under the first and second years of the cropping period and under fallows of varying length, and assuming these represented sequential stages of a cycle. The primary aim of the study was to measure losses of soil, carbon and nitrogen by erosion. Erosion under tree cover was at very low rates. Under crops, there is difficulty in reconciling the moderately high values given for erosion of total soil, and the percent carbon in eroded sediments, with the low values stated for annual losses of organic matter through erosion, and compromise values were adopted.

Table 4. Shifting cultivation, The philippines: record of input data.

DOCUMENTATION

FILE NAME: B:KELL6901
TITLE: SHIFTING CULTIVATION, PHILIPPINES
SOURCE: KELLMAN, 1969
COUNTRY: PHILIPPINES
LOCATION: MINDANAO
NOTES: DATA ON SOIL VS CARBON EROSION INCOMPATIBLE
ASSUMPTIONS FOR OUTPUT: HALF INITIAL CARBON SLOW-DECAY, IGNORED; Kt=0.35
DATE OF INPUT: 2.2.87
DATE OF OUTPUT: 12.3.87

Physical Environment

CLIMATE=	Lowland Humid
SOIL=	Medium textured
SLOPE=	Steep

Agroforestry System

AGROFORESTRY SYSTEM=	Rotational
YEARS UNDER TREE=	15
YEARS UNDER CROP=	3
STARTING WITH=	Crop

Soil Conditions

SOIL DEPTH CONSIDERED FOR CARBON (cm)=	20.
INITIAL SOIL CARBON (kg/ha)=	36000.
INITIAL CARBON FRACTION IN TOPSOIL=	0.036
TOTAL SOIL DEPTH (cm)=	200.

Erosion

RAINFALL FACTOR=	1000
ERODIBILITY FACTOR=	0.10
SLOPE FACTOR=	2.00
TREE COVER FACTOR=	0.001
CROP COVER FACTOR=	0.100
SOIL EROSION UNDER TREE=	200.
SOIL EROSION UNDER CROP=	20000
TREE PROPORTIONALITY FACTOR=	0.80
CARBON ENRICHMENT FACTOR=	2.00

Plant Growth

TREE, NET PRIMARY PRODUCTION=	20000.
CROP, NET PRIMARY PRODUCTION=	3000.

NPP OF PLANT PARTS

PART	TREE	CROP
Leaf	6400.	2000.
Fruit	400.	1000.
Wood	13200.	0.
Root	8000.	1200.

Table 4. (continued)

CARBON (AS FRACTION OF BIOMASS), TREE=		0.50	
CARBON (AS FRACTION OF BIOMASS), CROP=		0.50	
CARBON FRACTION RETAINED (GROWTH) ANNUALLY			
.	PART	TREE	CROP
.	Leaf	0.00	0.00
.	Fruit	0.00	0.00
.	Wood	0.24	0.00
.	Root	0.20	0.00
CARBON FRACTION RETAINED (GROWTH) AT CUTYEAR			
.	PART	TREE	CROP
.	Leaf	0.00	0.00
.	Fruit	0.00	0.00
.	Wood	0.00	0.00
.	Root	0.00	0.00
FRACTION OF ROOTS TO BELOW SOIL DEPTH CONSIDERED			
.	PART	TREE	CROP
.	Root	0.50	0.50
.		TREE	CROP
CARBON/GROWTH FEEDBACK FACTORS=		0.50	1.00
DEPTH/GROWTH FEEDBACK FACTORS=		0.50	1.00

Additions

ORGANIC ADDITIONS TO TREE (kg/ha/yr)=	0.0
ORGANIC ADDITIONS TO CROP (kg/ha/yr)=	0.0
CARBON AS FRACTION OF ORGANIC ADDITIONS=	0.50

Removals

PERIOD AFTER WHICH THE TREE IS CUT (years)=		15	
FRACTIONS REMOVED ANNUALLY			
.	PART	TREE	CROP
.	Leaf	0.00	0.00
.	Fruit	0.00	1.00
.	Wood	0.00	0.00
.	Root	0.00	0.00
ADDITIONAL FRACTIONS REMOVED AT CUTYEAR			
.	PART	TREE	CROP
.	Leaf	1.00	0.00
.	Fruit	1.00	0.00
.	Wood	1.00	0.00
.	Root	0.00	0.00

Assumptions about soil/plant processes

LOSS FROM ABOVE-GROUND PARTS IN CONVERSION TO HUMUS=	0.85
LOSS FROM ROOTS IN CONVERSION TO HUMUS=	0.67
LOSS FROM ORGANIC ADDITIONS IN CONVERSION TO HUMUS=	0.67
NUMBER OF HUMUS FRACTIONS CONSIDERED=	One Fraction
MEDIUM-DECAY HUMUS:	
K UNDER TREE=	0.035
K UNDER CROP=	0.040

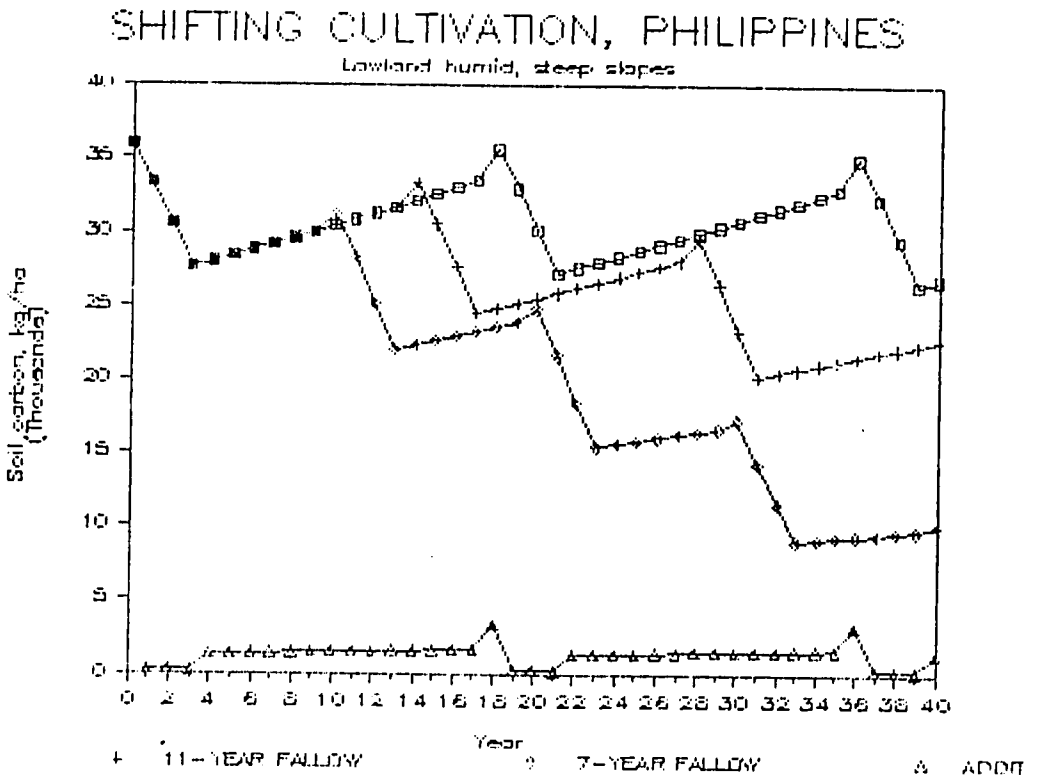


Figure 9. Shifting cultivation, The Philippines: Changes in soil carbon. The upper line, for 3 years cultivation followed by 15 years forest fallow, is based on data in Kellman (1969). The two lower lines show the simulated effects of reducing the fallow to 11 and 7 years. The line near the base shows annual additions to soil carbon from plant litter; the rise in the last year is the effect input to the soil of accumulated root growth, in reality probably distributed over succeeding years.

The example was modelled first as a rotational system with 3 years under crops followed by 15 years under trees; to illustrate soil recovery over two cycles, the output period was extended to 40 years. Subsequently, the possible effects of increasing population pressure were simulated by reducing the fallow period to 11 and 7 years.

The reported values of soil carbon are quite high, and if it is assumed that all of this suffers oxidation loss of 3% per year, then the reported rates of litter fall are insufficient to achieve build-up of soil carbon during the fallow. By assuming that 50% of the initial soil carbon is slow-decay form, an equilibrium over the 18-year cycle was achieved. This was modelled not by taking the two-humus fraction assumption, but by assuming the slow-decay fraction to be virtually unchanging and thus halving the initial soil carbon entered. The data are given in Table 4.

Results The results of three runs of the model are shown in Figure 9. Taking the upper curve, for a 15-year fallow, a rapid decline in carbon over the cropping period is followed by a build-up during the fallow; the apparently greater litter addition during the last year arises from decomposition of the roots of felled trees. A long-term steady state is achieved.

The two lower curves show effects of reducing the fallow successively to 11 and 7 years. Cultivation recurs before soil carbon has returned to its initial level, and the cycle is degrading.

In the case of the 7-year fallow, an accelerating rate of degradation with successive cycles can be seen, the result of the feedback effect of poorer plant growth and faster erosion on the degraded soil.

Discussion The general situation shown in Figure 9 has long been recognized; curves of this kind were first constructed in 1960 (Nye and Greenland, 1960, p. 105). Shifting cultivation, ecologically stable under low population densities, became a degrading system where the fallow is shortened whilst management practices remained unchanged.

The same approach can be applied to an agroforestry system of improved rotational fallowing. This is one of the few agroforestry practices in which there is no tree/crop interface, the tree/crop interaction taking place by transfer of soil fertility over time. It retains, however, the elements of possible production (e.g of fuelwood) from the tree, and soil fertility improvement. In agroforestry research into spatial systems, such as alley cropping, it would be valuable to add trials of rotational improved fallow for comparison.

5.5 Sensitivity tests

It may be asked, how sensitive is the model to changes in value of different input variables? This is a matter of significance to agroforestry design, since it relates to questions of the type, "If we altered the value of X, what would be the probable effect?"

To investigate this, a standard basic situation was set up in which the soil carbon remained exactly constant. Taking lowland subhumid climate with a gentle slope, and a spatial agroforestry system of 40% trees, 60% crops, with crop residues retained, this stable situation was achieved by lowering the crop NPP from its default value of 9000 to 3770 kg DM/ha/yr (leaving the tree NPP at default level). The carbon feedback factor was set to zero.

Different input variables were then increased and decreased by 10% in relative terms (e.g. roots as a proportion of above-ground biomass changed from 0.40 to 0.44 and 0.36), the model was run for a 20-year period, and the resulting rise or fall in soil carbon was recorded. The latter was converted to a percentage change from initial soil carbon.

The results are shown in Table 5. The first two rows refer to the spatial structure of the system. If the tree crop ratio is changed by 10%, soil carbon after 20 years changes by about 4-5%; the rise with increase in tree area is basically because all tree litter is retained whereas crop fruit is removed. If the area under trees is increased but that under crops kept constant, the soil response is about half as large.

The next three rows in Table 5 refer to rates of plant growth. Finding a tree species that will produce 10% more biomass raises 20-year soil carbon by over 5%. Crop growth has less effect, and this would be still smaller where residues were removed. Errors in estimating roots, as a proportion of above-ground biomass, have a large effect, since root matter from both trees and crops passes into the soil, and with an assumed lower humification loss than for above-ground litter.

The next three rows concern erosion. For the gentle slope used in this test, 10% changes in the rate of erosion or the carbon enrichment factor produce relatively little effect. On steep slopes the consequences would be much greater. Changing the tree proportionality factor has a larger effect; this is because raising or lowering the factor by 10% alters the predicted rates of erosion by considerably more, allowing less or more weight respectively to the rapid erosion under the crop component.

The last two sensitivity tests for a spatial system refer to the main constants in the soils section of the model. The largest effect is that of the carbon loss during initial conversion from plant litter to soil humus: a 10% error in estimating this causes nearly an 8-9% difference in predicted soil carbon after 20 years. Raising or lowering the decomposition constants for soil humus (the proportion of existing soil carbon lost by oxidation in one year) has substantial effects. These two critical values are not likely to be studied in standard agroforestry experimental work, but require specialized studies, including by means of carbon-isotope labelling.

Table 5. Sensitivity test. Effects of 10% increases and decreases in values o input variables on soil carbon after 20 years.

Variables increased or decreased by 10%	Percent difference in soil carbon after 20 years	
	Rise	Fall
Spatial system:		
Increase area under tree and decrease area under crop conversely	4.2	4.9
Increase area under tree but leave area under crop unchanged	2.6	2.5
Increase tree net primary production	5.2	4.9
Increase crop net primary production	3.7	3.6
Increase roots as fraction of above-ground biomass	5.8	5.6
Increase tree proportionality factor in erosion	4.3	4.3
Increase rate of soil erosion	1.2	1.2
Increase carbon enrichment factor in erosion	1.2	1.2
Decrease litter-to-humus conversion losses (above-ground and roots)*	9.0	8.3
Decrease decomposition constants (tree and crop)	7.8	7.2
Rotational system:		
Increase time under tree as percent of tree-crop cycle	7.1	6.7

*Taken as 10% increase in proportion converted, net proportion lost.

The last row of Table 5 refers to a rotational agroforestry system. A period of 3 years under crop was compared with a tree fallow of 2, 3 (standard) and 4 years, run for complete tree-crop cycles of 20, 18 and 21 years respectively, the data standardized to a 20-year period and the results adjusted to give imaginary 10% changes in the R factor (cultivation years/total cultivation-plus-fallow). The resulting soil differences are about 7%.

Other variables cannot be converted into terms of percentage change. Taking the same basic, initially stable, system as above, Table 6 shows the effects of removing, instead of retaining, tree leaf litter, crop residues, and both. The consequences are substantial. If tree litter is removed, e.g to feed to livestock, it is considerably more difficult to design a stable agroforestry system. Retaining crop residues which are currently removed could have as great a beneficial effect on soil carbon as planting a tree component.

It is well-known that adding farmyard manure improves soil organic matter status. In this set of circumstances, the addition of 1 t/ha/yr (entered into the model as 300 kg DM/ha/yr) raises soil carbon after 20 years by nearly 5%. This offers some potential for agroforestry systems in which tree leaf litter is removed as livestock feed. In this example, however, 2 t/ha/yr is required to compensate for the removal of tree litter, a level of farmyard manure production which is frequently not practicable for the whole of a farmer's land. If crop residues are also removed, the unrealistically high rate of 4 t/ha/yr manure is required, a result in agreement with earlier research into arable cropping.

Some elements of the model, notably the effect of the decomposition constant, have a self-regulating or homeostatic tendency. Thus if erosion is ignored and the carbon feedback factor set to zero, some equilibrium level of soil carbon is approached whatever the input conditions. Other elements have the effect of magnifying changes and can lead to an unstable system. The carbon feedback factor is one such element, but the greatest effects are produced through erosion. An initially degrading system can lead to an accelerating cycle of declining soil fertility - poorer plant growth - greater erosion - faster decline in soil fertility, leading to a situation with no remaining topsoil carbon and ultimately complete loss of soil. Such a cycle has not infrequently been observed in reality!

5.6 Applying SCUAF to non-agroforestry land use systems

Although designed for the basic agroforestry situation of tree and non-tree components, the SCUAF model can be applied to other land use systems by manipulation of the inputs. This can be useful in comparing the consequences of proposed agroforestry systems with existing land use, particularly where information is available on soil changes under the present use. Some devices for such applications are as follows.

Table 6. Effects of removals and additions of organic material on soil carbon after 20 years, for a system initially in equilibrium.

Variable changed	Percent change in soil carbon after 20 years
Remove tree leaf and fruit	- 9.5
Remove crop residues	-10.3
Remove tree leaf, fruit and crop residues	-19.8
Add 1 t/ha/yr farmyard manure (3000 kg DM/ha/yr)	+ 4.6
Remove tree leaf, fruit, add 1 t/ha/yr farmyard manure	- 4.9
Remove tree leaf, fruit, add 2 t/ha/yr farmyard manure	- 0.0
Remove tree leaf, fruit and crop residues, add 4.33 t/ha/yr farmyard manure	- 0.0

Natural vegetation Treat as a rotational land use system, with the tree component coming first and continuing for a long period (e.g. 99 years). Enter data from ecological studies as the tree net primary production. The crop production data can be changed to zero for purposes of clarity, although they will have no effect on the model.

Examples are given in Figure 10. Those labelled forest and savanna are derived from data in Lelong et al. (1984). This source is exceptional in giving not only soil erosion but measured carbon erosion and the carbon enrichment ratio; the data on plant growth are rather rudimentary. Using default values for soil processes, the model simulates the presumed steady state of these systems.

The fourth example is based on a study of highland forest in the Usambara Mountains, Tanzania (Lundgren, 1978). This is the most nearly complete set of data, for any kind of land use, in all the published studies consulted. Not only is litter fall measured but there are attempts to estimate the growth increment of trees, timber fall and root production. Soil data are complete, with carbon percentage and bulk density by 10-cm layers. Erosion is not measured but can be assumed from the circumstances to be low.

Under any reasonable assumptions, it is difficult to prevent the modelling of this system showing a progressive increase in soil carbon. The author notes that biomass production, by comparison with other forest ecosystems, is unusually high. He also assumes that the forest shows a net increment in biomass during the period of observation, and it may thus be the case that the soil also has not reached equilibrium.

Plantation forestry Suppose trees are grown on a 25-year rotation, and then felled and replanted. This can be modelled as a rotational system, with 25 years under tree followed by 1 year under "crop", where "crop" represents the year of replanting and its growth is set to zero. It is possible to input substantial erosion during the "crop year", i.e. from felling the trees, if this is expected to occur.

In some forest plantations, biomass production by the undergrowth is substantial. Such a situation can be modelled as a spatial mixed system, with tree and crop cover both 100% and the estimated biomass production from the undergrowth entered as the crop component.

Such a method fails to take account of removal of biomass in thinnings. If it is the net soil change over the cycle as a whole that is of interest, these could be carried forward and combined with the main timber harvest.

Reclamation forestry A forest cover may be planted as a means of restoring degraded lands, initally with no harvest, the objective being restoration of soil fertility. This can be modelled as a rotational system commencing with a long period under the tree component and with no removals. Initial soil carbon is low and initial plant growth may be slow. A simulated output is shown in Figure 11. Soil organic matter builds up, whilst the operation of the carbon feedback factor leads to faster plant growth.

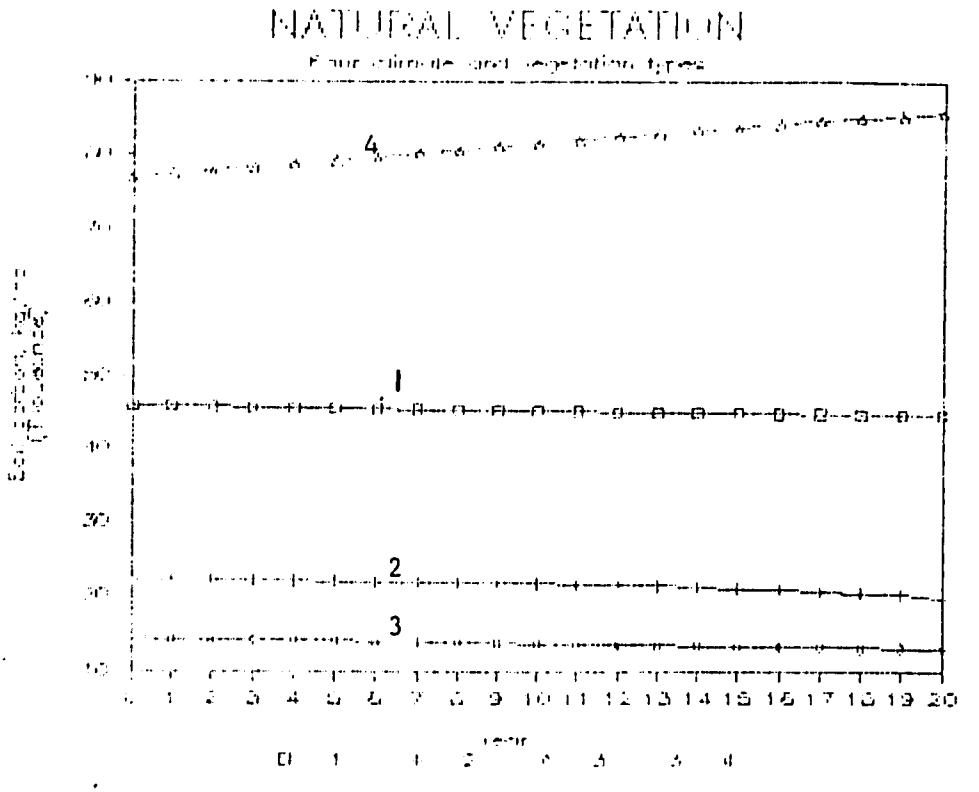


Figure 10. Soil carbon under natural vegetation. 1: Lowland rain forest, Ivory Coast. 2: Moist savanna, Ivory Coast. 3: Dry savanna, Burkina Faso. 4: Highland forest, Tanzania. Sites 1-3 are stable under default assumptions on processes, whereas Site 4 accumulates soil carbon. Data for 1-3 from Lelong et al. (1984), for 4 from Lundgren (1978).

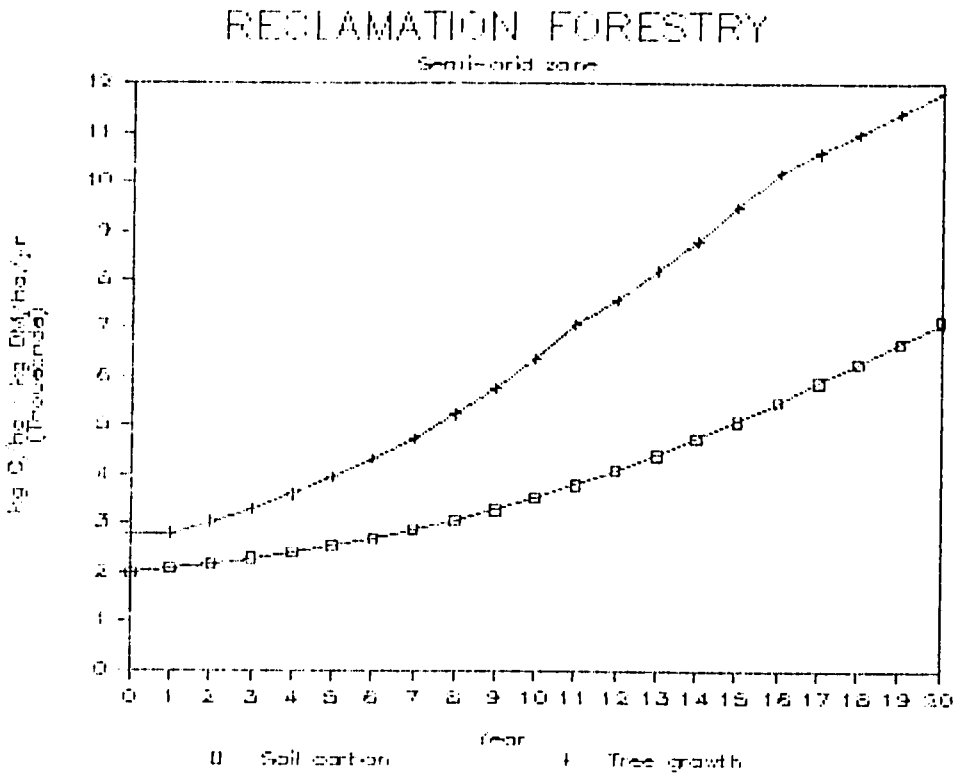


Figure 11. Soil carbon and tree growth under reclamation forestry. Data are simulated. The initial conditions are set at low soil carbon and slow plant growth, with a carbon feedback factor of 2.0 to represent improvement in rate of tree growth in response to build-up of soil organic matter. The feedback factor is reduced to 1.0 after 10 years and 0.5 after 15 years (combining 3 runs of the model). After Year 20, soil carbon approaches an equilibrium value of about 8000 kg/ha.

Agriculture: annual crops Treat as a rotational system, with the crop component coming first and continuing for a long period. Enter crop data, and set tree growth to zero.

An example is given in Figure 12, based on data for cropped plots under similar conditions to the forest site in Figure 10 (Lelong et al., 1984). Under continuous cultivation, soil organic matter declines steadily for the reported situation of a gentle slope. Simulating the faster erosion for a moderate slope, the rate of soil degradation becomes catastrophic, all carbon being lost after 9 years.

Agriculture: perennial crops The manner of modelling crops such as oil palm, rubber or tea will differ according to the plant composition and management of the system. Where essentially only one plant is present, as in a tea, it can be treated as a rotational system, with "years under crop" representing the period of replanting or a grass break. Where there is a substantial understorey, it can be treated as a spatial mixed agroforestry system, with the main plantation crop as the tree and the undergrowth entered as the crop component, both with a cover of 100%.

Grazing systems In principle, these can be modelled as rotational systems, with crop first and for a long period, the "crop" being the pasture plants. Pasture consumption by livestock could be treated as a removal or "harvest", and estimated manure production as an organic addition. Root production is particularly important in such systems.

Attempts were made to model published studies of soil organic matter cycling under grasslands, but difficulties were encountered in interpretation of the data. Readers with access to data are invited to try to apply the model to such systems.

5.7 Applying SCUAF to complex agroforestry systems

In the case of spatial agroforestry systems, the model assumes that the soil becomes homogenized as between areas under tree and crop, through even distribution of litter. This may not always be the case. For example, it is possible that some alley cropping systems will lead to belts of soil richer in organic matter along the tree rows.

Where it is thought that this may occur, the model should be run separately for the tree and crop areas, treating each as a rotational system with an initial long time period. The tree leaf matter is entered as a removal in modelling the tree area, and as an organic addition for the crop area.

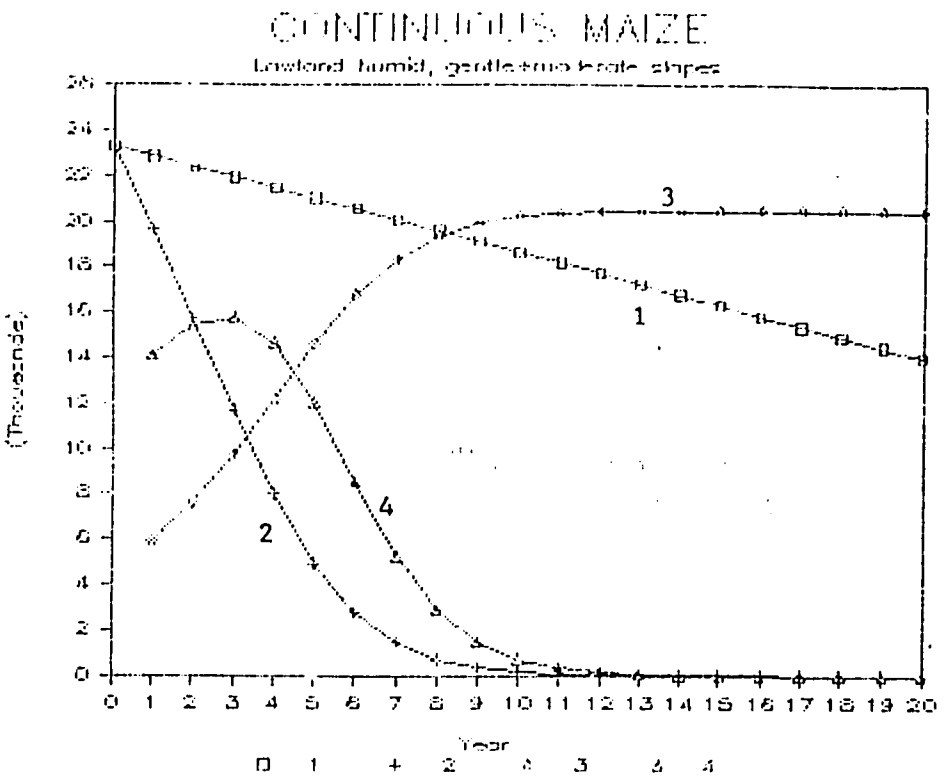


Figure 12. Soil carbon and erosion under maize monoculture. Based on data in Lelong et al. (1984). 1: Soil carbon, gentle slope, kg/ha. 2: Soil carbon, moderate slope, kg/ha. 3: Soil erosion, moderate slope, kg/ha/yr (÷ 30). 4: Carbon erosion, moderate slope, kg/ha/yr (x 4).
With a gentle slope, soil carbon declines continuously. With a moderate slope, decline is rapid, and after 7 years, crop yield (not shown) has fallen to 300 kg/ha. Soil erosion increases as plant cover is reduced, stabilizing at the rate on bare soil, 600 t/ha/yr. Carbon erosion initially rises, then falls as the topsoil becomes depleted of carbon. After 20 years, this soil has lost 70 cm of profile depth; in reality, gully erosion would probably have commenced.

The present functioning of the model imposes constraints on the combinations of plants and management which it is possible to simulate. In particular, it is not possible to treat agroforestry systems with substantial elements of both spatial combination and rotation, nor to model, in one run, a situation in which the land use system is of one kind for a number of years, after which the structure or management is changed. There is no provision for year-to-year changes in the rate of tree growth.

In due course, it is intended to extend the programming of the model to permit such complications to be entered; specifically, to allow a run to be halted after any chosen number of years and modified data entered. This will give greater flexibility, and allow the effects of factors external to the model, e.g. shading or moisture availability, to be entered. In the meantime, many such situations can be modelled by means of two or more runs, with data transferred from one to the other manually, viz:

i. Run the model for the initial situation. Obtain the standard outputs of soil carbon, erosion, biomass production and harvest, as printed tables.

ii. Enter the predicted soil conditions, erosion and plant growth from the last year of the above run as the initial conditions for a second run.

iii. Enter the details of the structure and management of the new system, and proceed with a second run.

iv. Combine the two runs into a single time sequence, as tables and graphs. This can be done manually or by importing one stored spreadsheet onto another.

It is even possible to change the land use and management year by year, by means of a succession of model runs of one year's duration, manually transferring data from one run to another.

Whilst such devices may appear clumsy by comparison with the rapid operation of the standard model, they occupy only a few hours at most.

An example is given in Figure 13, for a situation which supposes the arrest of a degrading system of pure agriculture by the introduction of agroforestry. The degrading system is that from Figure 12, based on real data, the agroforestry a hypothetical spatial system with 40% trees, which substantially reduces erosion.

One of the best-known agroforestry sytems, taungya, is also one of the most complex to model. It is a spatial mixed system for the first 2-3 years, then becomes rotational with a long period under the tree component only; moreover, crop yield declines in successive years of the cropping period because of tree shading, a factor not included in SCUAF (models are becoming available for this).

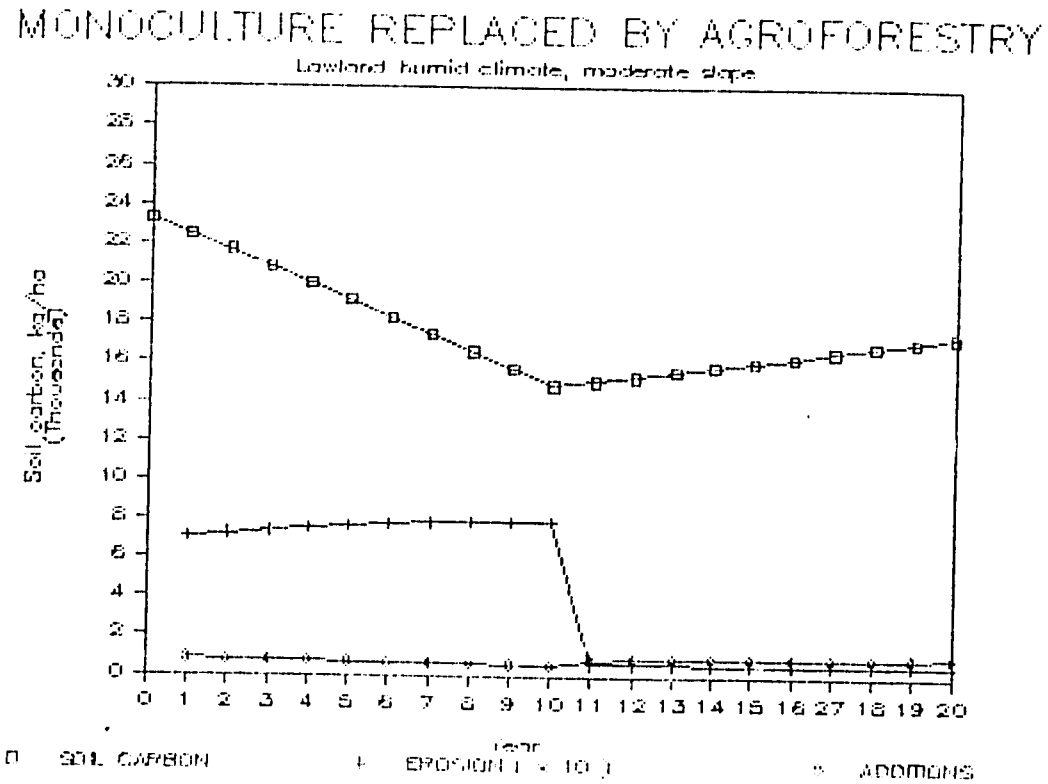


Figure 13. Soil carbon under maize monoculture replaced by agroforestry. Years 1-10 monoculture, based on observed data (Lelong et al., 1984), taking a slope angle intermediate between the two values in Figure 12. From Year 11 onwards, this is replaced by an agroforestry system of 40% trees, 60% crops, all environmental data remaining the same. Soil degradation is checked and reversed by agroforestry, through a large reduction in erosion coupled with an increase in plant litter additions.

The effects of a taungya system on soils can be predicted by averaging the crop yield over the cropping period, running this as a spatial system of short duration, then re-entering the data as the start of a second run under trees only. Thus the supposed cyclic change in soil properties under Kenya's taungya (locally called shamba) system as given by Robinson (1976) could be investigated if adequate data were obtained.

5.8 Using SCUAF for purposes of agroforestry system design

5.8.1 Introduction

Necessarily, the examples given here have been based on the retrospective simulation of systems for which data are already available. The intention of the model, however, is predictive, to aid in the design of agroforestry systems by estimating whether they will achieve the major component of sustainability, maintenance of soil fertility.

Two basic situations can be envisaged: that in which a research station or other institution is intending to start field research into agroforestry for the first time, and that in which such a research programme is already under way.

5.8.2 Starting agroforestry research

Let us assume that a diagnosis and design exercise has identified decline in soil fertility, caused by erosion or over-cropping, as an important basic problem in the area under study. Agroforestry appears to have a potential to assist in solution of this problem, and a research programme is being planned. It is important that the systems designed should be productive as well as sustainable. Moreover, they must meet many requirements or constraints unrelated to soil conditions, e.g. supply fuelwood or an additional source of cash income.

Two problems common to agroforestry experimental work are the time needed and complexity. Clear results are unlikely to be obtained in a period of less than five years, at a minimum. The complexity arises from the large number of variables involved, e.g. tree and crop species, tree spacing, and tree and crop management; a replicated trial of every combination of circumstances could run to many hundreds of plots, although economies are possible by confounding of variables or systematic designs.

Given this situation, it is desirable to focus field research upon systems which it is supposed, from ex ante analysis, will function most efficiently (sometimes called "best bet" systems). This applies a fortiori to on-farm trials. Many tools of analysis, including computer models, are becoming available to investigate different aspects, e.g. for modelling the effects of shade, moisture availability, and the economics of the systems. The SCUAF model is intended as a means to investigate which systems will be sustainable from a soils aspect.

The first step is to obtain relevant existing data. Do not depend upon default values except where necessary: they are very broad approximations, intended as a fallback only. Study the results of non-agroforestry experimental work for the area, or for similar climatic, soil and slope conditions. In particular, make best estimates of the growth rates of multipurpose trees. There may be previous soil monitoring studies, e.g. research conducted for the purpose of studying effects of length of fallows. These basic data on plant growth and soil response are the foundation on which predictions of the SCUAF model rest. Observed data for the local area, even if weakly supported or provisional, are to be preferred to the use of default values.

A range of agroforestry designs can then be modelled, with the same inputs of plant growth and soil constants but varying the spatial or temporal structure of the system and the management, particularly removals.

For example, lengths of time under trees and crops could be compared for systems of improved fallow, tree densities compared in spatial mixed systems, and relative areas under trees and crops in spatial zoned systems. The consequences of retaining or harvesting particular plant components can be investigated, e.g. retaining or removing tree prunings.

It would be wrong to select a particular agroforestry design solely on the basis of its potential to sustain soil fertility. Many other considerations will influence acceptable designs, e.g. a shortage of livestock feed, the need to take account of moisture competition, or a viable economic return. Agroforestry systems design is a matter of compromise between conflicting requirements. Modelling will permit prediction of whether a specific system, which meets such non-soil specifications, is acceptable from the point of view of sustaining soil fertility.

5.8.3 Modifying existing designs

An alternative situation, becoming increasingly common, is that early results from agroforestry experimental work are already available. It is to be hoped that these will include results from soil monitoring. If not, sampling of present conditions and comparison with some presumed initial state is better than nothing.

In this situation the existing experimental results should be entered into SCUAF, and run for all combinations of values for which data exist. By modifications to the constants, particularly the humification conversion loss and the decomposition constants, an attempt should be made to simulate the observed soil changes. The outcome will probably be ranges, rather than single values.

The values which lead to successful predictions of the observed states can then be used to investigate modifications to design. These could be changes to an observed sustainable design called for by non-soil considerations, or changes to a system desirable in other respects but which is not currently sustaining soil fertility.

5.8.4 Collecting data for improved future predictions

In either of the above situations, there is one further use of the SCUAF model, namely to indicate what data should be collected in order to model changes in soil carbon. Most agroforestry experiments are likely to collect data on rates of tree leaf, fruit and wood growth, crop yield and crop residues. Data also needed, but at present frequently absent or deficient, are:

i. Statistically-controlled monitoring of soil changes.

ii. Estimates of root production and turnover.

iii. Improved estimates of the rates of litter-to-humus conversion loss and humus decomposition.

Techniques for measuring root production are time-consuming, but even limited and approximate observational data are better than pure speculation.

Estimates of root turnover, litter conversion and humus oxidation are not likely to be made in the course of normal agroforestry experimental work, in which they must be derived by simulation of observed changes. They can be studied directly by the technique of carbon-isotope labelling (Vose, 1980). There are relatively few studies of tropical soils using this technique and more are desirable, possibly conducted through cooperation with external organizations possessing specialized facilities.

5.9 A final word of caution

When operating with computerized models it is easy to get carried away. The results look so plausible, and internally consistent, that one is in danger of believing that they represent reality.

Predictions from models are only as good as the data fed into them. The sensitivity of the SCUAF model to changes in data and constants has been indicated above. The model can be of value in the almost infinite saving of time, as between sitting at a computer for a day and running field trial for 5 years or more.

It is, however, essentially an adjunct to experimental work, not a substitute. As every farmer knows, what matters about an agroforestry or any other land use system is whether it functions well in the field.

6 USER'S GUIDE TO SCUAF

6.1 Introduction

This section is a guide to the use of the SCUAF submodel for carbon cycling and erosion. It should be read in conjunction with the description of the nature and functioning of the model, given in Section 2.

6.2 Getting started

The hardware requirement is for an IBM-compatible computer using the MS-DOS operating system, with a minimum of 256 kB of RAM memory, and with either twin drives for 5.25 inch diskettes or a hard disc and one such drive. The user is supplied with a diskette containing the file SCUAF.EXE.

If using twin diskette drives, place the diskette containing the file SCUAF.EXE in Drive A. Place a blank formatted diskette in Drive B; this is to hold data files.

If using a hard disk, copy file SCUAF.EXE onto the hard disk and proceed similarly. Whichever hardware system is used, there must be a blank formatted diskette in Drive B.

Ensure that system control is with Drive A. Type SCUAF and press the return key. After a few seconds, the MENU will appear on the screen (cf. Fig. 3, p. 24). All input, output and other operations commence from, and return to, this MENU. To finish a session from the MENU, type 99 and press the return key.

All operations described below are followed by pressing the return key. This will no longer be stated.

Pitfalls As in all computer programs, there are some pitfalls, places where the user unfamiliar with operation can easily go wrong. Those which are so far recognized are marked in the text below by being enclosed between *** marks. No doubt there are others!

6.3 Inputs

General For the first run of a model, the user will normally work through inputs 1 to 9 in sequence. However, as a minimum to ensure correct operation of the programme, it is essential when starting a new model to proceed through inputs 2 to 6, in that order.

After the above has been done, the user can enter and leave any input option individually, without affecting data outside that option. This allows a set of alternative runs to be made with different assumptions as to one or a few variables, e.g. to answer questions such as, "suppose we could raise rate of tree net primary production from 10,000 to 12,000 kg/ha/yr, what effect would this have?"

Units With a few exceptions (indicated by screen prompts), all data are in kg/ha or kg/ha/yr. The basic unit is carbon (C), except that following normal practice, plant material is expressed as dry matter (DM).

Gathering data The first step is to collect all required data, using photocopies of the input form (Table 7). This should be done with as much thoroughness as possible, taking considerably longer than the subsequent running of the model. Users may wish to add indications of the relative reliability of different items of data, e.g. M = measured, E = estimate (moderately reliable), G = guess, D = use of default value.

Input 1. Documentation This input has no effect upon the operation of the program, but can be used as a form of heading to identify outputs.

FILE NAME. If the data contained in this run of the model is stored (option 96), this is the disk drive and file name under which it will be held. Any legimimate file name can be used, but the following are recommended:

- Commence with B: so that data storage will be on the disk in Drive B.
- Continue with up to 6 characters, as a mnemonic based on the title.
- Continue with two numbers, representing successive runs of the same model with modifications to data or assumptions.
- Use the extension .SCU to indicate a SCUAF data file.

Thus B:BUNDA02.SCU would indicate Run No. 2 of data based on a site at Bunda.

TITLE. Any short title, up to 40 characters. Capital letters are suggested. E.g.:

- BUNDA ALLEY CROPPING PLOT 5
- ARANGUREN ET AL. (1982)

COUNTRY. ---

LOCATION. E.g. name of research station; up to 40 characters.

NOTES. Anything can be entered, up to 120 characters. Typically, this will be an amplification of the title.

ASSUMPTIONS FOR OUTPUT. Up to 120 characters. This is intended for noting different assumptions in successive runs, e.g. "With all tree leaf matter harvested", "Root production set at 50%".

DATE OF INPUT. DATE OF OUTPUT. These serve as a reminder of the state of knowledge, and possibly also assumptions, at times of data input (or revision) and most recent output.

Table 7. SCUAF DATA INPUT FORM

FILE NAME:
TITLE:
SOURCE:
COUNTRY:
LOCATION:
NOTES:

DATE OF INPUT:
DATE OF OUTPUT:

Physical Environment

CLIMATE =
SOIL =
SLOPE =

Agroforestry System

SPATIAL or ROTATIONAL

FRACTION OF LAND COVERED BY TREE =
FRACTION OF LAND COVERED BY CROP =

YEARS UNDER TREE =
YEARS UNDER CROP =
STARTING WITH =

Soil Conditions

SOIL DEPTH CONSIDERED FOR CARBON (cm) =
INITIAL SOIL CARBON (kg/ha) =
INITIAL CARBON FRACTION IN TOPSOIL =
TOTAL SOIL DEPTH (cm) =

Erosion

RAINFALL FACTOR =
ERODIBILITY FACTOR =
SLOPE FACTOR =
TREE COVER FACTOR =
CROP COVER FACTOR =
SOIL EROSION UNDER TREE (kg/ha/yr) =
SOIL EROSION UNDER CROP (kg/ha/yr) =
TREE PROPORTIONALITY FACTOR =
SOIL EROSION (kg/ha/yr) =
CARBON ENRICHMENT FACTOR =

Plant Growth

TREE, NET PRIMARY PRODUCTION (kg DM/ha/yr) =
CROP, NET PRIMARY PRODUCTION (kg DM/ha/yr) =
NPP OF PLANT PARTS (kg DM/ha/yr)

PART	TREE	CROP
Leaf		
Fruit		
Wood		
Root		

CARBON (AS FRACTION OF BIOMASS), TREE =
CARBON (AS FRACTION OF BIOMASS), CROP =

FRACTION RETAINED (GROWTH) ANNUALLY

PART	TREE	CROP
Leaf		
Fruit		
Wood		
Root		

FRACTION RETAINED (GROWTH) AT CUTYEAR

PART	TREE	CROP
Leaf		
Fruit		
Wood		
Root		

	TREE	CROP
FRACTION OF ROOTS BELOW DEPTH CONSIDERED =		
CARBON/GROWTH FEEDBACK FACTOR =		
DEPTH/GROWTH FEEDBACK FACTOR =		

Additions

ORGANIC ADDITIONS TO TREE (kg/ha/yr) =
ORGANIC ADDITIONS TO CROP (kg/ha/yr) =
CARBON AS FRACTION OF ORGANIC ADDITIONS =

Removals

PERIOD AFTER WHICH THE TREE IS CUT (years) =

FRACTIONS REMOVED ANNUALLY

PART	TREE	CROP
Leaf		
Fruit		
Wood		
Root		

ADDITIONAL FRACTIONS REMOVED AT CUTYEAR

PART	TREE	CROP
Leaf		
Fruit		
Wood		
Root		

Assumptions about soil/plant processes

LOSS FROM ABOVE-GROUND PARTS IN CONVERSION TO HUMUS =
LOSS FROM ROOTS IN CONVERSION TO HUMUS =
LOSS FROM ORGANIC ADDITIONS IN CONVERSION TO HUMUS =
NUMBER OF HUMUS FRACTIONS CONSIDERED =
MEDIUM-DECAY HUMUS : K UNDER TREE =
K UNDER CROP =

TWO-FRACTION ASSUMPTION ONLY:
SLOW-DECAY HUMUS : K UNDER TREE =
K UNDER CROP =
FRACTION OF INITIAL CARBON IN SLOW-DECAY FORM =
FRACTION OF PLANT PARTS BECOMING MEDIUM-DECAY HUMUS:

PART	FRACTION
Leaf	
Fruit	
Wood	
Root	
Orgads	

FRACTION OF MEDIUM HUMUS TRANSFORMED ANNUALLY TO SLOW =

Input 2. Environment This input is for the purpose of setting those default values which are dependent on climate, soil or slope. It is not intended as a full record of the physical environment under which an experiment is conducted, for which purpose the ICRAF Environmental Data Base is recommended (Young, 1985a).

CLIMATE. Definitions are in terms of Koeppen climatic classes. The values for altitude and rainfall are approximate guidelines.

SCUAF class	Koeppen classes	Vegetation zone
1. Lowland humid	Af, Am	Rain forest
2. Lowland subhumid	Aw	Savanna
3. Lowland semiarid	BSh	Semi-arid (sahel)
4. Highland humid	Cf, Cm	Highland forest
5. Highland subhumid	Cw	Highland savanna
6. Highland semiarid	BSk	Highland semiarid

For Koeppen definitions and an identification key, see Young (1985a, p.53). Very approximate guidelines are:

Highland/Lowland division at about 1200 m near equator, falling to sea level at about 30 N and S latitudes.

Humid:	Rainfall over 1500 mm, with less than 4 dry months.
Subhumid:	Rainfall 600-1500 mm, with 4-8 dry months.
Semiarid:	Rainfall under 600 mm, with 8 or more dry months.

SOIL. Broad texture class. Leave at the default setting of medium textured unless known to be clearly sandy (sand, loamy sand) or clayey (clay, heavy clay).

SLOPE. Modified from the slope classes of the FAO Soil Map of the World:

Slope class	Predominant slopes	
Flat	0-1°, 0-2%	(depositional landforms, e.g. flood plains, deltas)
Gentle	1 -5°, 2-8%	
Moderate	5 -17°, 8-30%	
Steep	over 17°, over 30%	

Input 3. Land use system This input covers arrangement of the tree and crop components in space or time.

Spatial:	Tree and crop components are arranged in space
Rotational:	Tree and crop components alternate in time.

The model cannot at present handle systems in which there is both a spatial and a rotational element (but see Section 5.7).

Spatial systems: enter the proportions of the land surface covered by the tree and crop components.

Enter as a proportion of 1.0, not a percentage, e.g. 0.4, not 40%.

Rotational systems: enter the number of years under tree and crop, and which comes first.

Input 4. Soil Initial soil conditions.

SOIL DEPTH CONSIDERED FOR CARBON (cm): The user may choose to model carbon present down to any depth in the profile. Use of the topsoil (plough/hoe layer), to 15 or 20 cm, is recommended.

INITIAL SOIL CARBON (kg/ha): Obtain if possible from data on soil analysis. The value entered is the mass of carbon down to the depth specified above. Unfortunately, data on bulk density are rarely given. Typical values are:

	Bulk density	Weight of 1% carbon per cm horizon thickness
Topsoil	1.0	1000 kg/ha
Lower horizons	1.5	1500 kg/ha

E.g. if the top 20 cm are considered, and analysis gives 1.8% carbon for this horizon, the initial soil carbon is 1.8 x 1000 x 20 = 36 000 kg/ha. ***Use carbon, not total organic matter.***

INITIAL CARBON FRACTION IN TOPSOIL. Used for calculating erosion loss. Source data will be as a percentage value, but ***it must be entered as a fraction, e.g. 1.8% as 0.018.***

TOTAL SOIL DEPTH (cm). This is required for calculating the effects of loss of profile depth through erosion.

Input 5. Erosion Users will differ widely in the extent of data available to them. Some will have measured erosion rates on experimental plots, or have access to locally-determined values in the universal soil loss equation; others may have little reliable information, and be seeking approximate estimates based on readily-available data.

The same causative factors can be used in both cases. They differ in the degree of sophistication with which values of the factors have been determined. The alternatives are given below, going from the more detailed to the more generalized.

Caution. The rainfall (R) and soil (K) factors are dependent on units of measurement; either both must be metric, or both non-metric.

R FACTOR:

- Calculate from meteorological records.
- Obtain from published maps, based on records.
- Estimate as the modified Fournier Index, p /P, where p = monthly rainfalls and P = mean annual rainfall (FAO, 1979, p. 43).
- Use the approximation, R = 0.5 x mean annual rainfall.
- The model gives default values based on 0.5 times an assumed average annual rainfall for the climatic zone.

K FACTOR:

- Use the value for the soil type determined by experimental work.
- Where soil analytical data are available, obtain from the nomograph in the USLE (Wischmeier and Smith, 1978, p. 11; Landon, 1984, p. 312) or its metric version.
- Where the soil class and texture are known, use values taken from Table 8.
- The model gives default values based on soils of moderate erodibility in the Table 8.

S FACTOR:

- Enter values taken from the USLE table for the slope length and angle under consideration (Wischmeier and Smith, 1978, pp. 12-13; Landon, 1984, p. 314).
- Use values in Table 9. Where not known to the contrary, 100 m may be taken as a standard slope length.
- The model gives default values for the slope classes given in FAO (1979).

C FACTOR:

The cover factor is entered separately for the tree and crop components.

- Enter a cover factor based on the full USLE method of calculation.
- Enter typical values of cover factors taken from Roose (1977) or FAO (1979) (Table 10)
- The model gives default values based on FAO (1979).

SOIL EROSION UNDER TREE and UNDER CROP. The model now calculates erosion separately for the tree and crop components, and displays these (as kg/ha/yr, not the unit often used in erosion studies, t/ha/yr). The user may change these values. This ends the erosion input for rotational systems.

TREE PROPORTIONALITY FACTOR (spatial systems only). For explanation, see Section 2.5.2

SOIL EROSION. The rate of erosion is displayed for spatial systems, calculated from the rates under tree and crop components combined according to the tree proportionality factor. The user may change this value, e.g. when erosion under the agroforestry systems has been measured.

Table 8. Generalized values of the soil erodibility factor (K) for FAO soil classes (FAO, 1979).

	Erodibility of soil types		
	Low	Moderate	High
All:	Chernozems	Kastanozems	Podzoluvisols
"	Ferralsols	Greyzems	Vertisols
"	Rendzinas		Xerosols
"	Phaeozems		Yermosols
"	Lithosols		
"	Nitosols		
"	Histosols		
"	Arenosols		
"	Rankers		
Acrisols:	Ferric	(other)	Plinthic
	Humic		
Cambisols:	Ferralic	(other)	Gelic
	Humic		Vertic
Gleysols:	Calcaric	(other)	Gelic
	Humic		
	Mollic		
Fluvisols:	Calcaric	(other)	Thionic
Luvisols:	Ferric	(other)	Albic
			Plinthic
			Vertic
Podzols:	-	Humic	(other)
		Leptic	
Regosols:	Calcaric	(other)	Gelic
Solonetz:	-	Mollic	(other)
Andosols:	Mollic	(other)	-
	Humic		
Planosols:	-	Mollic	(other)
		Humic	
Solonchaks:	Mollic	(other)	Takyric

Soil erodibility factors

		Erodibility of soil type		
		Low	Moderate	High
Texture class:	Sandy	0.1	0.2	0.4
	Medium	0.15	0.3	0.6
	Clayey	0.05	0.1	0.2

Table 9. Generalized values of the slope factor (S). Based on Wischmeier and Smith (1978).

Slope		Slope Length (m)		
Percent	Degrees	50	100	200
2	1	0.2	0.3	0.4
4	2	0.5	0.7	0.9
6	3	0.9	1.2	1.7
8	5	1.3	1.8	2.5
10	6	1.8	2.5	3.5
15	9	3.3	4.6	6.5
20	11	5.2	7.5	10.0
25	14	7.5	11.0	15.0
30	17	10.0	15.0	20.0
40	22	16.0	23.0	34.0
50	27	23.0	36.0	45.0

Table 10. Generalized values of the cover factor (C).

A. Based on FAO (1979)

	Percentage ground cover					
	0-1	1-20	20-40	40-60	60-80	80-100
Pasture grassland and rangeland	.45	.32	.20	.12	.07	.02
Woodland with appreciable undergrowth	.45	.32	.16	.18	.01	.006
Woodland without appreciable undergrowth	.45	.32	.20	.10	.06	.01

	Climate		
Crops	Humid	Subhumid	Semi-arid
	0.4	0.6	0.8

B. Based on Roose (1977)

Bare soil (reference)	1.0
Dense forest	0.001
Savanna in good condition	0.01
Savanna, burnt or overgrazed	0.1
Cover crops	0.01 to 0.1
Maize, sorghum, millet (as a function of yield)	0.4 to 0.9
Cotton, tobacco	0.5
Groundnuts	0.4 to 0.8
Cassava, yams	0.2 to 0.8
Oil palm, rubber, cocoa with cover crops	0.1 to 0.3
Pineapple: residues burnt or buried	0.1 to 0.5
residues on surface	0.01

Input 6 Plant growth

TREE, NET PRIMARY PRODUCTION CROP, NET PRIMARY PRODUCTION	The above-ground annual biomass production (growth) of each plant, as kg/ha/yr dry matter

If there is more than one tree species, enter an average, weighted according to area covered, and similarly for crops.

If crop yield is known but not biomass, an approximate NPP can be obtained by making use of the typical harvest index for the crop. For cereals, above-ground biomass is roughly 3 x grain yield.

The "per hectare" in this input refers to a hectare of tree only or hectare of crop only. It does not refer to a hectare of total land within a spatial agroforestry system. A decision had to be made one way or the other. If, therefore, your data is for plant biomass production within the system as a whole, this must be divided by the fractional areas covered. This is perhaps the most dangerous pitfall in the inputs, and it is essential to understand the situation. For example:

Alley cropping system, spatial: area under tree 0.2
area under crop 0.8
Measured biomass production for the system as a whole:
tree 4000 kg/ha/yr
crop 6000 kg/ha/yr (grain, c.2000 kg)
The values entered under net primary production are then:
tree, 4000/0.2 = 20 000 kg/ha/yr
crop, 6000/0.8 = 7 500 kg/ha/yr

NPP OF PLANT PARTS. The model displays values based on an allocation by default of the net primary production. The user should replace these with measured values of leaf, fruit, wood and root wherever possible. LEAF includes all herbaceous matter, FRUIT all reproductive matter, WOOD all woody matter (not usually present in crops), root all or most underground matter.

There are problems in allocating: (i) below-ground harvested parts (whether biologically roots or not), e.g. potatoes, cassava; (ii) below-ground tree stemwood. It does not matter which way the user allots these, provided it is made consistent with removals (Input 7).

Root biomass production will often not be known. The default value for both tree and crop is 40% of above-ground production.

CARBON AS FRACTION OF BIOMASS, TREE AND CROP. By default, this is assumed to be 0.5, i.e. 50%. This value can be changed.

FRACTION RETAINED (GROWTH) ANNUALLY. Three things can happen to the annual biomass production of any plant part:

- removed (harvest, or other loss);
- retained as growth;
- returned to the soil.

Removals are specified under Input 8. "Retained as growth" means the biomass that remains in the living plant at the end of the year---the normal meaning of "growth"---expressed as a fraction of the annual biomass production. If the crop is an annual, this is 0.0 for all parts. For the tree, the default assumptions are 0.0 for leaf and fruit (all are shed annually), 1.0 for wood (all retained as growth), and a speculative guess of 0.67 for root (one third shed to soil, two thirds remain) as growth.

FRACTION OF ROOTS GROWING BELOW SOIL DEPTH CONSIDERED. If only the topsoil is being considered, some of the root biomass will be in the lower soil horizons and thus not enter the soil carbon system being treated. Default assumptions are 0.6 (=60%) for tree roots and 0.4 for crop roots.

Measured litter production Some studies, particularly of natural ecosystems, report measured litter fall rather than plant growth. Provision to enter this was included in a development version of the model, but was found to lead to a danger of errors. Where litter fall is known, it can be used to derive functions retained as growth, i.e:

Amount retained as growth = Net primary production - litter fall

Fraction retained as growth = Amount retained as growth/Net primary production.

This can be calculated separately for each plant part.

FRACTION RETAINED (GROWTH) IN CUTYEAR. Often, no plant parts will remain as living plants in a cutyear. Where there is coppicing or pollarding, however, a proportion of the tree wood and root will remain.

CARBON/GROWTH FEEDBACK FACTORS: TREE, CROP. See Section 2.6. If soil carbon falls by 1.0%, enter the proportional reduction in rate of plant growth, e.g.:

Change in plant growth per 1% change in soil carbon	Carbon growth feedback factor
1.0%	1.0
0.5%	0.5
nil	0.0

DEPTH/GROWTH FEEDBACK FACTORS. The corresponding effect on plant growth of loss of profile depth by erosion.

Input 7. Additions For the carbon submodel, this refers to organic additions only: farmyard manure, compost, or mulch for external origin.

ORGANIC ADDITIONS TO TREE (kg DM/ha/yr)
ORGANIC ADDITIONS TO CROP (kg DM/ha/yr)

CARBON AS FRACTION OF ORGANIC ADDITIONS. By default, 0.5.

Note that farmyard manure is normally expressed in units of net weight, whilst dry matter is entered into the model. Manure consists of about 30% dry matter, thus 1 tonne farmyard manure is entered as 300 kg DM.

As with NPP above, "per hectare" refers to a hectare of tree or crop alone. In rotational systems, the model will make these additions only when the plant concerned (usually crop) is present. In spatial systems, they must be adjusted for area covered, in the same way as NPP.

Have you fed tree fodder to livestock, and returned farmyard manure to the soil? If so, both these are treated as external flows. Enter the tree leaf as removals (Input 8); then enter the farmyard manure as organic additions.

Input 8. Removals The removals are an important element in the agroforestry system. For example, they show whether tree leaf litter is removed to feed livestock, or retained to pass via litter to the soil. Losses other than harvest (e.g. burning, direct browsing) are combined with harvest as removals.

PERIOD AFTER WHICH THE TREE IS CUT (years). This is the concept of the cutyear. Its primary purpose is to indicate when the tree component, having been allowed to grow, is felled, coppiced or pollarded. It can also be used for any additional removal that takes place once every so often.

Cutyears must recur regularly. If there is no such distinctive year, enter either 1 or 100. For rotational systems, enter the same as the length of the period under tree.

FRACTIONS REMOVED ANNUALLY. Fractions (often 1.0 or 0.0) of each plant part are harvested, or otherwise removed (burn, browse) annually. Crop fruit (= grain, etc.) will normally be removed (enter 1.0). Crop leaf (residues) may be removed (enter 1.0) or returned to the soil (enter 0.0), and similarly tree leaf (removed as livestock fodder or not). Be consistent with the allocations made under "plant parts".

ADDITIONAL FRACTIONS REMOVED IN CUTYEAR. What extra is harvested, or burnt, in a cutyear? E.g. tree wood, as fuelwood.

The cutyear removals specified are additional to the annual removals; i.e. in a cutyear, both annual and cutyear removals take place. Do not double-count, or the model may "extract" carbon from the soil, i.e. add negative values!

Input 9. Assumptions about soil/plant processes The data in this section are not likely to be obtained during standard agroforestry experimental work. They require specialized studies, often involving the use of isotope tracers. Users who are not soil scientists may omit this input entirely, in which case the default assumptions will run.

These are:

One humus fraction	
Conversion losses, litter to humus:	
above-ground plant parts	0.85
roots	0.67
organic additions	0.67
Decomposition constant of humus:	
under tree	0.03
under crop	0.04

Users should note that these values are known only very approximately, and that differences in them can have substantial effects on soil carbon levels. One way of handling this situation is to run the model, for the same data in other inputs, with several different values for process constants.

LOSS FROM ABOVE-GROUND PARTS ON CONVERSION TO HUMUS
LOSS FROM ROOTS ON CONVERSION TO HUMUS
LOSS FROM ORGANIC ADDITIONS ON CONVERSION TO HUMUS

The proportions of organic carbon that are lost to the atmosphere, as CO_2, during conversion from plant residues to humus.

NUMBER OF HUMUS FRACTIONS CONSIDERED

The use of the one-fraction humus assumption is recommended, owing to the paucity of knowledge about the behaviour of the slow-decay fraction (Section 2.4.3).

DECOMPOSITION CONSTANTS: MEDIUM-DECAY HUMUS: UNDER TREE
UNDER CROP

The proportion of soil humus carbon that is lost annually by microbial oxidation. It is expressed as a fraction, e.g. 0.03, not 3%. For spatial systems the model weights the values according to areas covered by tree and crop.

There is no provision in the model for leaching of carbon. In podzols, notional values could be added to the decomposition constants.

The remaining process inputs refer to slow-decay humus, and values are speculative. Screen prompts are self explanatory.

6.4 Outputs

6.4.1. Introduction

As with the inputs, each output procedure, selected from the menu, is independent. This allows the user to provide one complete set of inputs, obtain outputs, and then change a single value of input, or a small number of values, and see what is the effect.

In practice, all parts of the model --- carbon flows, and changes in soil properties, erosion and plant growth --- for every year called for are calculated; whichever output has been specified is then displayed.

Outputs are initially to the screen. By the usual MS-DOS practice of pressing CONTROL+P they can be directed additionally to a line printer.

6.4.2. Outputs giving a record of input data (Table 2)

Output 11. Documentation This displays the file name, title and other basic information from Input 1. It can be used as a form of heading to identify other outputs, e.g. printed above a table or graph.

In particular, when making several runs with the same data, it is convenient as a record of minor changes, e.g. "As Run 01 but with tree leaf litter removed".

Output 12. All variable settings This gives a record of all the values input to the current run of a model. It should be directed to the printer, as it scrolls off the screen.

***Having completed a set of inputs, users are urged to:

- Store the input data (see section 6.4.6).
- Obtain a printout of variable settings.
- Switch off the computer, go away from it, and thoroughly check the data.

Much time can be wasted by proceeding further without having checked that data have been correctly input.***

6.4.3 Outputs showing flows of carbon.

Output 13. Display detailed carbon flows
Output 14. Display summarized carbon flows

Users are not normally expected to employ these outputs. They show the movements of carbon through the plant section of the model for any specified year. If one of the regular outputs is not giving the values anticipated, these displays can be used to see how the carbon additions to soil are derived, e.g. for the first year, a non-cutyear or a cutyear. They should be directed to the printer. The format is less user-friendly than that of other outputs.

6.4.4 Outputs showing changes in soil conditions and plant response

Examples are given in Table 2. As well as being sent to screen printer, these outputs are automatically recorded on the data diskette in drive B, for subsequent graphical output.

Output 15 Changes in soil carbon This is the fundamental output for which the SCUAF model was designed. The user is prompted to enter the initial year, normally 1, and the final year for which output is required. A period of 20 years maybe taken as standard. Outputs for short periods, e.g. 5 years, will show whether the soil carbon trend is upward or downward. It is not recommended normally to extend predictions to longer than 20 years, as the feedback effects may substantially change the initial conditions and assumptions on which the input data have been based.

For the case in which one humus fraction is assumed, the tabular output shows:

TIME :	Year number
CARBON:	Soil humus carbon, kg/ha
OXIDATION:	Loss of soil carbon by microbial oxidation to CO , kg/ha/yr
EROSION:	Loss of carbon in eroded soil, kg/ha/yr (cf. changes in erosion, below)
ADDITION:	Carbon additions to soil humus by decomposition of plant residues, kg/ha/yr

The calculation of carbon in successive years can be seen by inspection:

CARBON(t+1) = CARBON(t) - OXIDATION(t) - EROSION(t) + ADDITIONS(t)

Where t and t+1 refer to successive years.

If two humus fractions are assumed, the tabular headings are as follows:

TIME:	Year number
MEDIUM:	Medium-decay soil carbon, kg/ha
SLOW:	Slow-decay soil carbon, kg/ha
TOTAL:	Total soil carbon, kg/ha
MEDOXN:	Oxidation loss of medium-decay carbon, kg/ha/yr
SLWOXN:	Oxidation loss of slow-decay carbon, kg/ha/yr
EROSN:	Loss of carbon in eroded soil, kg/ha/yr (assumed to be of medium-decay carbon)
TRANS:	Transformation of medium-decay to slow-decay soil carbon, kg/ha/yr
ADDN:	Carbon additions to soil humus by decomposition of plant residues, kg/ha/yr

If the user has specified any additions of plant residues directly to slow-decay humus, these are applied to the functioning of the model but are not distinguished in the output.

Output 16. Changes in erosion Changes in soil carbon lead to changes in the soil erodibility factor, K; whilst changes in rates of plant growth, as a consequence of the feedback factors, will affect the cover factors, under tree, Ct, and under crop, Cc. These changes in factors will alter the predicted rate of soil erosion.

Where the amount of carbon in the soil has been reduced or increased, it is assumed that the carbon content of the topsoil, and thus of eroded soil, changes proportionally. Hence changes in soil erosion and carbon erosion are not necessarily pro rata; in particular, under conditions of severe erosion, soil erosion may steadily increase owing to less plant cover, but carbon erosion may fall to low values or zero, as the topsoil becomes depleted of carbon.

Where the user has altered the predicted soil erosion during input, a hidden correction factor is carried forward to calculations in future years.

The headings in the output table of changes in erosion are as follows:

T	Year
CLIMATE FACTOR:	C factor (in USLE or FAO equation); remains constant
EROD FACTOR:	K factor; changes with change in soil carbon
SLOPE FACTOR:	S factor; (= LS factor in USLE); remains constant
TREE COVER:	C factor for tree; changes with rate of tree growth
CROP COVER:	C factor for crop; changes with rate of crop growth
SOIL EROSION:	Erosion of total soil, kg/ha/yr
CARBON EROSION:	Loss of carbon in eroded soil, kg/ha/yr
SOIL DEPTH:	Depth of soil remaining, cm

Output 17. Changes in plant biomass production, as affected by soil
Through the operation of the carbon and depth feedback factors, the rates of tree and crop growth may change, with respect to the rates input for Year 1. This output shows such changes.

Units are dry matter prodution, as kg DM/ha/yr. The headings are largely self-explanatory. The last column, C+T, refers to CROP + TREE, i.e. total biomass production, above-ground and roots. The values given are for the agroforestry system as a whole, and thus reflect the proportional areas under tree and crop components. Thus in Table 2, the value of Crop NPP input was 6000 kg/ha/yr, partitioned into leaf 4000 and fruit 2000, and roots as a proportion of above-ground biomass were set at 0.4, giving root growth as 2400 kg/ha/yr. In this demonstration run, the crop component covers 75% of the ground, therefore these figures are reduced by 0.75, giving the values displayed of CROP LEAF 3000, CROP FRUIT 1500 and CROP ROOT 1800.

It must be emphasized that the table shows only those changes to rates of plant growth that result from changes in soil carbon and soil depth, in the manner specified by the user during input. Future rates of tree and crop growth are likely to be affected by numerous other factors, which are not included in the SCUAF model.

Output 18. Changes in harvest This shows those parts of the tree and crop components that are normally likely to be harvested, in kg DM/ha/yr. Values are for the agroforestry system as a whole, whereas the rates input are per unit of land under tree or crop respectively. Thus in the demonstration run, crop fruit (=yield) was input as 2000 kg/ha/yr, as per hectare of land under crop; but as the crop only occupies 75% of this agroforestry system, this is reduced in the output to 1500 kg/ha/yr. The headings are as follows:

T. FRUIT:	Harvest of the tree fruit
T. LEAF:	Removal of tree herbaceous matter, e.g. as livestock fodder
T. WOOD	Fuelwood harvest
C. FRUIT:	Crop harvest, e.g. grain yield; given as dry matter, and will therefore differ from "crop yield" where the latter is conventionally given as green matter or inclusive of water content.
C. LEAF:	Removal of crop residues; whether as livestock fodder or for other purposes.

In the demonstration run, the tree is pruned, and fuelwood harvested, annually. Where the tree component is allowed to grow and then felled, this will appear as a zero value for fuelwood harvest in non-cutyears and a harvest of the accumulated wood growth in cutyears.

6.4.5 Converting ouputs to graphical form

The table produced for changes in soil carbon, erosion, plant biomass production and harvest can be converted to graphical form, by means of the user's graph-plotting package. During output, they are automatically stored on the data disc in Drive B under the following names:

B:CARBON.PRN	Changes in soil carbon
B:EROSION.PRN	Changes in soil erosion
B:BIOMASS.PRN	Changes in plant biomass production
B:HARVEST.PRN	Changes in harvest

They are stored as spreadsheets, with the headings occupying the upper rows, followed by the data.

These files over-write the preceding run. It is not therefore possible to store several runs during one session of SCUAF. The user must therefore proceed as follows:

1. Ensure that the last outputs of carbon, erosion, biomass and harvest are for the period of years which it is wished to store or graph (e.g. 20 years).

2. Having obtained any or all four of these outputs, exit from SCUAF (Menu selection 99).

3. Either: Proceed immediately to obtain graphs.

Or: Within the operating system, RENAME these data files. If the input data are stored on file B:FILENAME.SCU, suggested names for storing output data are:

Carbon:	B:FILENAME.CAR
Erosion:	B:FILENAME.ERO
Biomass:	B:FILENAME.BIO
Harvest:	B:FILENAME.HAR

The user may import these spreadsheets onto any compatible graphics package. The outputs shown in this publication are obtained using the LOTUS 2 package.

Where colour plotting is available this will add greatly to the visual impact of the outputs. Brown is an obvious choice for soil carbon, carbon erosion, and also fuelwood harvest, green for plant litter additions to soil, tree biomass production, and tree leaf harvest, and red or other warning colour for soil erosion.

The user can, of course, graph these data in any way desired. The examples given in Figure 4 illustrate suggested basic formats, viz:

Changes in soil carbon: (one humus fraction):

- Plot soil carbon and additions, as a line graph
- Set the X (horizontal) scale from 0 years (initial conditions) to 20 years
- Set the Y (vertical) scale to about 5000 kg/ha above highest value plotted, to the nearest 5000
- Identify the agroforestry system in the main heading, and the type of output, "Soil carbon", as a secondary heading (alternatively vice versa, or use the file name as one of the headings.)

Changes in soil erosion:

- Plot soil erosion and carbon erosion, as a line graph.

For specialized erosion studies, changes in the K and C factors can also be plotted.

Changes in biomass production (as affected by soil):

- Plot tree biomass and crop biomass, as a bar graph (alternatively as a stacked bar graph, thereby indicating biomass production from the agroforestry system as a whole)

Changes in harvest:

- Plot selected types of harvest, as a bar graph (alternatively as a line graph).

The best graphical format for this output will differ according to the types of harvest, whether there is a cutyear, and whether the system is spatial or rotational. The example in Figure 4 shows two items only. If there is fuelwood harvest in a cutyear, this will be large in relation to the crop yield; it is more satisfactory to scale the crop yield so as to occupy some 50-75% of the vertical space on the graph, and allow the cutyear fuelwood harvest to exceed the upper scale limit. Where three or more harvest items are to be shown, a line graph is more satisfactory.

6.5 Saving and loading runs of the model

Menu option 96. Save current model to a disc file

Having input the data, it can be saved for future reference on the data file in Drive B. The default name which appears when this option is selected will be that entered as FILE NAME in Input 1.

Menu option 98. Load a new model from disc file

Any file that has been stored can be loaded to become the current model. A screen prompt requests the FILE NAME; the drive name and the extension must be included, e.g. B:FILENAME.SCU.

This will over-write any model previously in use, thus destroying the data unless it has been stored.

Menu option 99. Exit

This exits from SCUAF and returns to the operating system. It is also used to precede graph plotting.

Never forget

Are you pleased with your outputs? Having made some adjustments to that input data, perhaps, do they show what you expected? If so, please re-read, and take to heart, the final word of caution (p. 67).

REFERENCES

Aranguren, J., Escalente, G. and Herrera, R. (1982). Nitrogen cycle of tropical perennial crops under shade trees. I. Coffee. II. Cacao. Plant Soil 67, 247-269.

Bernhard-Reversat, F, Huttel, C. and Lemée, G., 1975. Recherches sur l'écosysteme de la forêt subsequatoriale de basse Côte-d'Ivoire. I-VII. Terre Vie 29, 169-264.

Bolin, B. and Cooke, R. B., 1983. The major biogeochemical cycles and their interactions. SCOPE Report 21. Chichester: Wiley.

Bosatta, E. and Ågren, G. I., 1985. Theoretical analysis of decomposition of heterogeneous substrates. Soil Biol. Biochem. 17, 601-610.

Cheatle, R. J., Muraya, P. and Young A., in press. Modelling soil changes under agroforestry. Proceedings Third Kenya National Soil and Water Conservation Workshop, Nairobi, September 1986.

Elwell, H. A., 1981. A soil loss estimation model for southern Africa. In: Soil conservation. Problems and prospects (ed. R. P. C. Morgan, Wiley, Chichester), 291-292.

FAO, 1979. A provisional methodology for soil degradation assessment. Rome, FAO.

Frissel, M. J. (ed.), 1977. Cycling of mineral nutrients in agricultural ecosystems. Agro-Ecosystems 4, 1-354.

Frissel, M. J. and Veen, J. A. van, 1982. A review of models for investigating the behaviour of nitrogen in soil. Phil. Trans. Roy. Soc. B296, 341-349.

Jenkinson, D. S. and Ladd, J. N., 1981. Microbial biomass in soil: measurement and turnover. In: Soil biochemistry (ed. E. A. Paul and J. N. Ladd, Dekker, New York), 415-470.

Jenkinson, D. S. and Rayner, J. H., 1977. The turnover of soil organic matter in some of the Rothamsted classical experiments. Soil Sci. 123, 298-305.

Kang, B. T., Wilson, G. F. and Sipkens, L., 1981. Alley cropping maize (Zea mays L.) and leucaena (Leucaena leucocephala LAM) in southern Nigeria. Plant Soil 63, 165-179.

Kang, B. T., Grimme, H. and Lawson, T. L., 1985. Alley cropping sequentially cropped maize and cowpea with Leucaena on a sandy soil in southern Nigeria. Plant Soil 85, 267-277.

Kellman, M. C., 1969. Some environmental components of shifting cultivation in upland Mindanao. J. Trop. Geogr. 28, 40-56.

Lal, R. and Greenland, D. J. (eds), 1979. Soil physical properties and crop production in the tropics. Chichester: Wiley.

Landon, J. R. (ed.), 1984. Booker tropical soil manual. London: Booker Agriculture International Ltd.

Lelong, F., Roose, E., Aubert, G., Fauck, R. and Pedro, G., 1984. Géodynamique actuelle de differents sols à végétation naturelle ou cultivés d'Afrique de l'ouest. Catena 11, 343-376.

Lundgren, B., 1978. Soil conditions and nutrient cycling under natural and plantation forests in Tanzanian highlands. Rep. For. Ecol. For. Soils 31. Uppsala: Swed. Univ. Agric. Sci.

Nair, P. K. R., 1984. Soil productivity aspects of agroforestry. Nairobi: ICRAF.

Nye, P. H. and Greenland, D. J., 1960. The soil under shifting cultivation. Tech. Commun. 51, Commw. Bur. Soils, Harpenden.

Paul, E. A. and Veen, J. A. van, 1978. The use of tracers to determine the dynamic nature of soil organic matter. Trans. 11th Int. Congr. Soil Sci., III, 61-102.

Robinson, J. B. D., 1976. The effects of exotic softwood crops on the chemical fertility of a tropical soil. E. Afr. Agric. For. J. 23, 175-191.

Roose, E. J., 1977. Érosion et ruissellement en Afrique de l'ouest. Vingt années de mesures en petites parcelles expérimentales. Paris: Trav. Doc. ORSTOM 78.

Rose, C. W., 1985. Developments in soil erosion and deposition models. Adv. Soil Sci. 2.

Smith, O. L., 1979. An analytic model of the decomposition of soil organic matter. Soil Biol. Biochem 11, 585-606.

Swift, M. J., Heal, J. W. and Anderson, J. M., 1979. Decomposition in terrestrial ecosystems. Oxford: Blackwell.

Veen, J. A. van, Paul, E. A. and Voroney, R. P. 1981. Organic carbon dynamics in grassland soils. 1-2. Canad. J. Soil Sci. 61, 185-224.

Vose, P., 1980. Nuclear techniques in agronomy and plant biology. London: Pergamon.

Wischmeier, W. H. and Smith, D. D., 1978. Predicting rainfall erosion losses---a guide to conservation planning. Washington DC: U. S. Agric. Dept Handbk 537.

Young, A., 1976. Tropical soils and soil survey. Cambridge: Cambridge Univ. Press.

Young, A., 1985a. An environmental data base for agroforestry. ICRAF Working Paper 5, revised edition.

Young, A., 1985b. The potential of agroforestry as a practical means of sustaining soil fertility. ICRAF Working Paper 34.

Young, A., 1986a. Effects of trees on soils. In: Amelioration of soil by trees (ed. R. T. Prinsley and M. J. Swift, Commw. Sci. Council, London), 10-19. Reprinted as ICRAF Reprint 31, (1986).

Young, A., 1986b. The potential of agroforestry for soil conservation. Part I. Erosion control. ICRAF Working Paper 42.

Young, A., in preparation. The potential of agroforestry for soil conservation. Part II. Maintenance of soil fertility. ICRAF Working Paper 43.

APPENDIX. OBTAINING AND USING THE SCUAF MODEL

Obtaining the model

ICRAF will make SCUAF available to outside users who possess the necessary hardware, and wish to use the model for agroforestry research. Requests may be made by institutes or by individual scientists. If made through the Director of an institute, please give the name of the scientist who will be primarily responsible for its use.

No charge will initially be made to national institutions in less-developed countries (ICRAF reserves the right to introduce a charge at a later date). For institutions in developed countries, and those in less-developed countries with external funding, there is a charge for US $20.00 to cover handling and postage costs. This may be sent with the request, in an internationally-negotiable form, payable to ICRAF, or a proforma invoice will be sent if required.

All requests, including those free of charge, must be accompanied by a blank 5.25 inch diskette, together with payment where applicable. They should be addressed to:

ICRAF
(attention Prof. A. Young)
P.O. Box 30677
Nairobi
Kenya

Using the model

Users are free to make use of SCUAF in publications or internal reports, making acknowledgements of this Working Paper and the program, the bibiliographic reference to which is:

Young, A. and P. Muraya, 1987. SCUAF: Soil Changes Under Agroforestry. A computer program. Nairobi: International Council for Research in Agroforestry (program on diskette).

A SCUAF User's Registration Form will be sent with the program. Users are invited to complete this, and subsequently to keep in touch with ICRAF with respect to the data to which they have applied the model, results obtained, and problems. Suggestions for improvement will be welcomed. It is hoped to build up an informal network of users, leading to improvements to the model, and possibly in due course a comparison of results obtained.