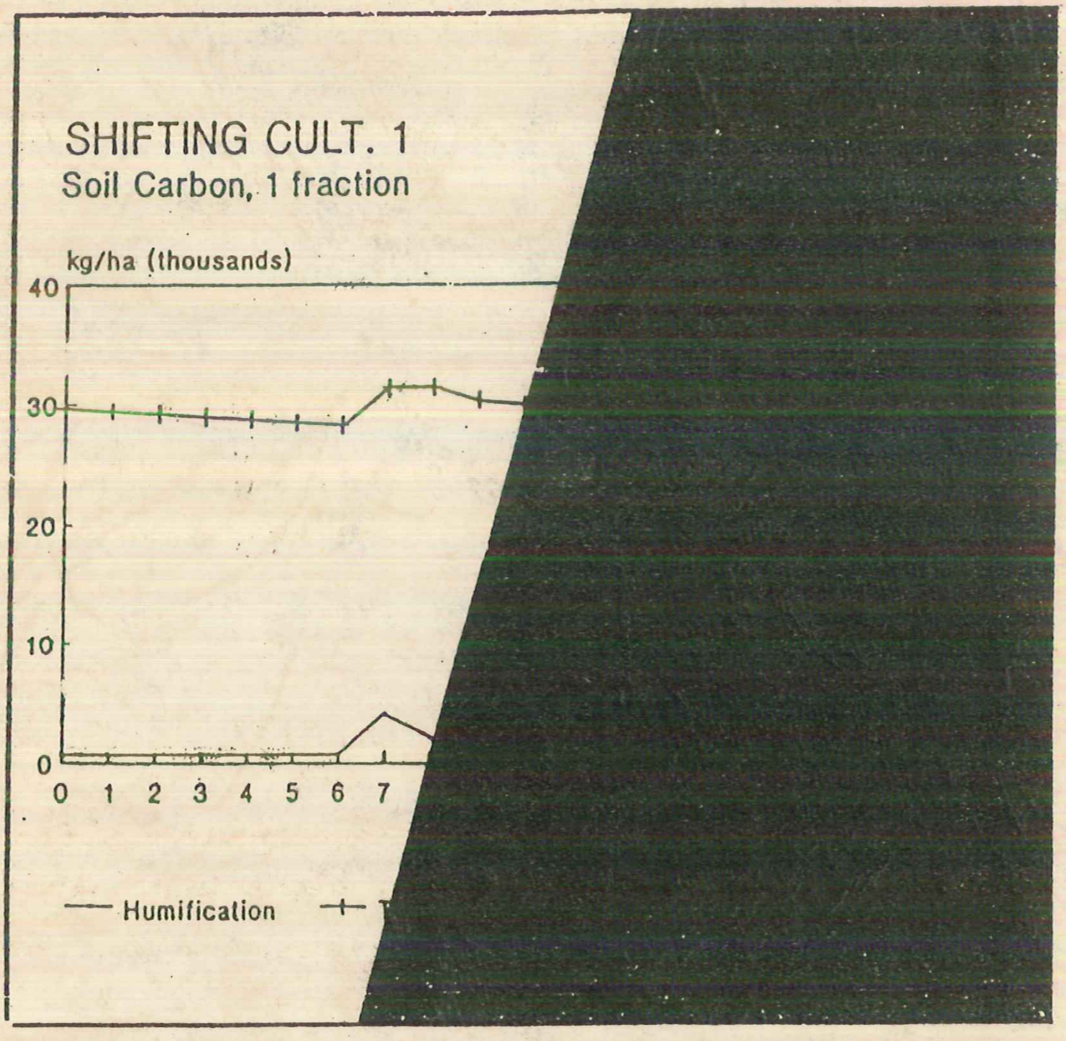
SCUAF

SOIL CHANGES UNDER AGROFORESTRY



COMPUTER PROGRAM WITH USER'S HANDBOOK

VERSION 2

Anthony Young and Peter Muraya

SCUAF

SOIL CHANGES UNDER AGROFORESTRY

A PREDICTIVE MODEL

VERSION 2

COMPUTER PROGRAM WITH USER'S HANDBOOK

Anthony Young and Peter Muraya

International Council for Research in Agroforestry
1990

Use of results from SCUAF

Users are welcome to make use of results from SCUAF in publications, citing this program with handbook as the source.

Copies of the program may be made within the institution to which the user belongs.

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Accompanying this handbook:

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2. An enlarged copy of the SCUAF input form.

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PART I. LEARNING TO USE SCUAF

1 INTRODUCTION AND OBJECTIVES

Introduction

In agroforestry systems, the tree component can fulfil both productive and service functions. Of the many products obtainable from trees, the most important in agroforestry are usually timber, fuelwood, fodder and fruit. The service functions include provision of shade (for humans and livestock), shelter from wind, fencing and boundary marking, and moisture conservation. However, for the less-developed world as a whole, the most important potential service role of agroforestry is certainly that of soil conservation. An account of this potential, with a summary of available evidence, has been set out by Young (1989).

In its older and narrower meaning, the term soil conservation meant protection against erosion. It is now recognized that what really matters is conservation of soil fertility, or the productive capacity of land. Prevention of erosion is one necessary condition for this, but it is equally important to conserve the soil organic matter and physical properties and, particularly for the low-input systems that characterize much of the less-developed world, soil nutrient content. Essentially, therefore, soil conservation means maintenance of soil fertility. Soil conservation is a major contributory factor to sustainable land use.

It is clearly desirable to be able to predict how soil properties will change under a specified agroforestry system on a given site, and to compare this with the effect of other land use systems, existing or proposed. If this could be done, it would offer a valuable technique for assessing the sustainability of proposed systems, to be used in conjunction with evaluation in economic and social terms.

Such predictions can only be made with confidence where based on evidence from field experiments. In recognition of the high apparent potential for soil conservation, a substantial part of current agroforestry research is directed towards this end, whilst many trials directed at other primary objectives include an element of soil monitoring.

An agroforestry field trial takes a minimum of 3-5 years to obtain useful results. Efficiency of design is important, particularly the identification of systems likely to achieve the results desired. Any possible aid to such design is therefore welcome.

Another need in field experimental work is to decide what measurements are to be taken. If the objective is maintenance of soil fertility, it is desirable to know what data are required in order to be able to understand, and therefore model and predict, the effects of different agroforestry systems upon the soil.

Furthermore, no field trial can include all possible combinations of variables, e.g. tree species, spacing, management, rotational elements. Once experimental data have been obtained, it would be useful to have a means of extending the results to estimate the likely soil impact of designs or treatments that have not been included, for example, if there had been fewer or more trees, or if crop residues had been removed instead of retained.

It was with these needs in mind that a computer model was constructed, **Soil Changes Under Agroforestry** or SCUAF. It is a relatively simple model, intended for use not only by soil specialists but by agroforestry research scientists in general. From the user's point of view, SCUAF is an interactive model: the user enters data in response to prompts on the screen, and selects the results required. Internally, SCUAF is primarily an input-output model, rather than the more sophisticated type of process-simulation model; it does represent soil-plant processes, but by means of relatively simple relations, dependent on the data supplied. Where data are missing, SCUAF contains a set of default data, specific to the chosen environment.

SCUAF operates on the basis of whole years; it does not simulate fluctuations in soil processes and properties within a year. Its outputs can be obtained for any length of time, from the short-term, 3-5 years, typical of an agroforestry field experiment, to the tentative investigation of soil trends in the long term, say 50 years. It is perhaps most applicable in investigating likely soil trends over medium-term periods, 10-20 years, a length of time which combines a good indication of sustainability with the limits of practical development planning.

Objectives

The primary purpose of the model is to predict the effects on the soil of specified agroforestry systems within given environments. This leads to a set of objectives, linked to applications of the model. The main objectives of SCUAF are:

1. To make approximate predictions of the effects upon the soil of specified agroforestry systems within given environments.

2. To show what data are needed from agroforestry experimental research if such predictions are to be made.

3. To make use of these predictions to assist in the design of agroforestry systems for research; either for selecting the most promising designs for initial trials, or for improving upon systems for which some data on performance are available.

4. To extrapolate data obtained from short-term experiments over longer periods, so as to obtain likely soil changes.

5. To indicate what advances on knowledge of soil-plant processes are needed in order to improve the accuracy of such predictions.

Objectives 2, 3 and 5 are cyclic to the primary objective 1: by field experimental research, collection of appropriate data and improvement in knowledge of processes, it will become possible to predict the effects of agroforestry systems upon soils with greater confidence.

Choice of erosion and the carbon and nitrogen cycles

SCUAF covers soil erosion, soil organic matter (represented as carbon) and nitrogen cycling. The control of erosion is essential for maintenance of soil fertility. Erosion leads not only to reduction in profile depth and ultimate loss of the entire soil, but losses of organic matter and plant nutrients in eroded sediment.

Soil organic matter, or humus, is fundamental to fertility. It is the main factor affected by management in determining soil physical properties. These in turn influence soil structure, root growth, water-holding capacity and resistance to erosion. Organic matter acts as a store of plant nutrients, held against leaching in organic molecules and progressively released into forms available to plants. This is particularly important in the low-input systems that characterize much of the less-developed world. The organic matter and nitrogen cycles are intimately linked. There are further beneficial effects of soil organic matter, such as reduced fixation of phosphorus and improved availability of micronutrients.

Nitrogen was selected for modelling because it is most frequently the limiting nutrient in tropical land use systems. An improvement in nitrogen supply nearly always produces an increase in crop yield. It is also a nutrient for which agroforestry holds a clear, established, potential through the use of nitrogen-fixing trees.

It is hoped in the future to extend SCUAF to the cycling of phosphorus, the next most common limiting nutrient in the tropics. It is not intended, however, to cover soil water, even though it is recognized that water is as vital to plant growth as nutrients, and also that agroforestry has a potential to improve soil water supply. However, the analysis of soil-plant water relations requires quite different techniques to those used in SCUAF, calling for modelling on a daily or weekly basis; it also, through rainfall variability, involves a stochastic (random or chance) element. SCUAF has an indirect relevance to water availability, in that it predicts changes in soil profile depth and organic matter, which are the main management-dependent causes of changes in soil water-holding capacity.

The rates of plant growth (trees and crops) at the start of a simulation, Year 1, are an input to the model. In this respect, it differs fundamentally from those models which simulate plant growth. Rates of growth (and therefore size of harvest) become modified in SCUAF only as a result of soil changes; the many other factors which can influence plant growth, such as rainfall fluctuations or pests and diseases, are not modelled.

Sources for the model

There have been many attempts to model plant-soil cycles. The most numerous are models of the nitrogen cycle, but there has also been substantial work on modelling of the carbon (or organic matter) and phosphorus cycles, and some on cycling of potassium and micronutrients. In addition, there are at least four models for the prediction of soil erosion.

The SCUAF method of erosion prediction is based on the simplification by FAO (1979) of the universal soil loss equation (Wischmeier and Smith, 1978). The primary basis for the SCUAF carbon cycle is that set out in Nye and Greenland (1960), which was combined with evidence from research using the technique of carbon-14 isotope labelling (reviewed in Paul and van Veen, 1978, and Young, 1989, p.110). Other carbon cycling models consulted include those of Bernhard-Reversat et al. (1975), Jenkinson and Rayner (1977), Smith (1979), van Veen et al. (1981), Brunig and Sander (1983), Bosatta and Agren (1985) and Parton et al. (1987). The SCUAF nitrogen cycle is derived from comparison of a variety of sources, including Frissel (1977), Rosswall (1980), Wetselaar et al. (1981), Robertson et al. (1982), Stevenson (1986) and Parton et al. (1987). Some of the similarities between the SCUAF carbon and nitrogen cycles and those of Parton et al. (1987) are the result of both models being independently derived from reviews of similar sources. Several studies on roots were consulted reviewed and, with references, in Young (1989, p.151).

Most of the above references are based on agricultural ecosystems. The first attempts to model carbon cycling under agroforestry systems were by Brunig and Sander (1983) and Young (1986). Version 1 of SCUAF, which covered carbon cycling and erosion only, was completed in 1987 (Young et al., 1987; Young and Muraya, 1988), and some applications have been given in Cheatle et al. (1989).

A word of caution

Computer models are very demanding in their requirements for data and for precise, numerical specification of processes. They need to know just what proportion of each quantity is transformed in which way (we have not attempted to incorporate the technique of fuzzy data sets). In written reviews, however, it is common to find statements to the effect that some process cannot be discussed because, although recognized to occur, it is difficult to measure. For example, there are very few published estimates of nitrogen losses through denitrification and volatilization, and for the process of symbiotic nitrogen fixation, it is hard to determine whether experts think that any of the fixed nitrogen sloughs off from nodules into the soil, as opposed to passing directly into the plant. The extreme of ignorance is reached in the case of the more stable, slow-decay, fraction of soil organic matter; it is known to exist, forms part of standard soil carbon analysis, but as regards its origins and rate of decay, G. K. Chesterton's poem on the microbe is applicable: 'Oh, let us never, never doubt/What nobody is sure about'.

In constructing SCUAF, assumptions have had to be made about the manner and rate of functioning of processes.. For some of these there are good data, for others, little and uncertain. Users should therefore treat results obtained from SCUAF with due caution. The greatest degree of reliability is where data are derived from actual agroforestry field experiments in which soil changes over a number of years have been monitored; the parameters in the model can then be adjusted to produce the observed results, prior to its application to different systems. At the time of writing there are very few such completed experiments. Next in degree of reliability are simulations based on real data for inputs, such as observed rates of plant growth and analytical data for initial soil properties. Least reliable are simulations which make extensive use of the default values in the model; the facility for doing this is valuable for using the model to explore different situations, and for training purposes, but real data or best estimates for the specific site under consideration should be substituted wherever possible. Computer models can be no better than the data on which they are based.

> In programming SCUAF, limits to the values of variables have not been set---as it is commonly said, the program has not been 'idiot-proofed'. It is therefore possible to obtain totally incorrect results if you have made some major slip entering data, for example entering 20000 as 2000, or 40 (as a percent) when the program asks for 0.4 (as a fraction).
>
> If you obtain results which look unlikely, carefully check the data for such errors.

The possible uses of SCUAF follow from the objectives. Some potential applications are:

USING SCUAF

- To design agroforestry systems for field trials. Which combination of variables (plant species, spacing, management, etc.) is most likely to be able to sustain soil fertility? Is a system that is based primarily on other requirements (e.g. fuelwood or fodder production) likely to be acceptable from a soil conservation point of view?

- To guide the measurements made in agroforestry experiments, so as to acquire the data needed to model and predict soil changes. Which data are the most critical, in that variations in their values have large effects upon the predictions?

- To investigate whether a proposed agroforestry system is likely to be sustainable, from the point of view of soil conservation.

- To extend data acquired from a field trial over a few years into an assessment of likely soil trends over 10-20 years.

- For exploratory conceptual work by research scientists. It is possible to ask questions about agroforestry-soil relations, and seek tentative answers to them from SCUAF.

- For agroforestry training. This has already been found practicable and useful. Participants at training courses rapidly learn to use the model, and it helps to make them think about why agroforestry systems assist in soil conservation, and what features (e.g. return of plant residues) are needed in order that they shall do so.

2 THE MODEL IN OUTLINE

Introduction

It is usually said that the components of agroforestry systems are trees or shrubs, crops or pastures, and livestock. SCUAF is primarily intended for analysis of agrosylvicultural systems, allowing only for treatment of livestock as an external element. In view of its objectives, however, the soil is clearly a focus.

The major components of agroforestry systems treated in SCUAF are therefore trees, crops and soils. The main processes modelled are soil erosion and the plant-soil cycles of carbon and nitrogen. These processes operate within a specified physical environment. The economic and social functions of agroforestry systems are not included, but can be linked with SCUAF through its specification of inputs (e.g. fertilizer) and outputs or harvest. Specifically, data derived from SCUAF can be entered into the MULBUD computer model, which is directed primarily at cost-benefit analysis (Etherington and Matthews, 1983).

The plant compartment

In any agroforestry system there are two plant components, trees (or shrubs) and crops, here referred to as **tree** and **crop** (Figure 1). The tree is partitioned into four parts, called **leaf** (herbaceous matter), **fruit** (reproductive matter), **wood** and **root**. Where it is an annual, the crop contains only leaf, fruit and root, but wood may be included to allow inclusion of perennial shrub crops such as coffee. **Organic additions**, such as compost or farmyard manure, may be brought in from outside the system and are treated thereafter as an additional plant part. The starting point for modelling is based on the annual net primary production, or biomass growth, of the eight plant parts (leaf, fruit, wood and root for tree and crop), together with the biomass in organic additions. For the remainder of the model plant biomass, as dry matter, is converted into its content of carbon and nitrogen.

The plant compartment, shown in the upper part of Figure 1, represents what happens to the various plant parts. Some are harvested annually: usually crop fruit and sometimes tree leaf (as fodder), tree fruit or crop leaf residues (as fodder or other uses). In some agroforestry systems the trees are allowed to grow for several years, increasing in woody biomass, and then felled or coppiced. This is known as a **cutyear**, a year in which the tree (or perennial crop) is 'cut' in some way (e.g. felling, coppicing), with an additional harvest. There can also be non-harvest losses of plant parts, such as burning.

Whatever is not harvested, or otherwise lost, passes out of the plant compartment and enters the soil compartment of SCUAF. All such material is called for convenience **litter**, which thus includes natural leaf fall, tree prunings, crop residues where added to the soil, and root residues. It is not always realized that many of the finer plant roots are cast off annually into the soil, the below-ground equivalent of leaf fall. Root residues play an important role in agroforestry systems (as can be shown by SCUAF). This litter, or plant material entering the soil, consists of about 50% carbon together with a very variable percentage of nitrogen, depending on the plant part and species.

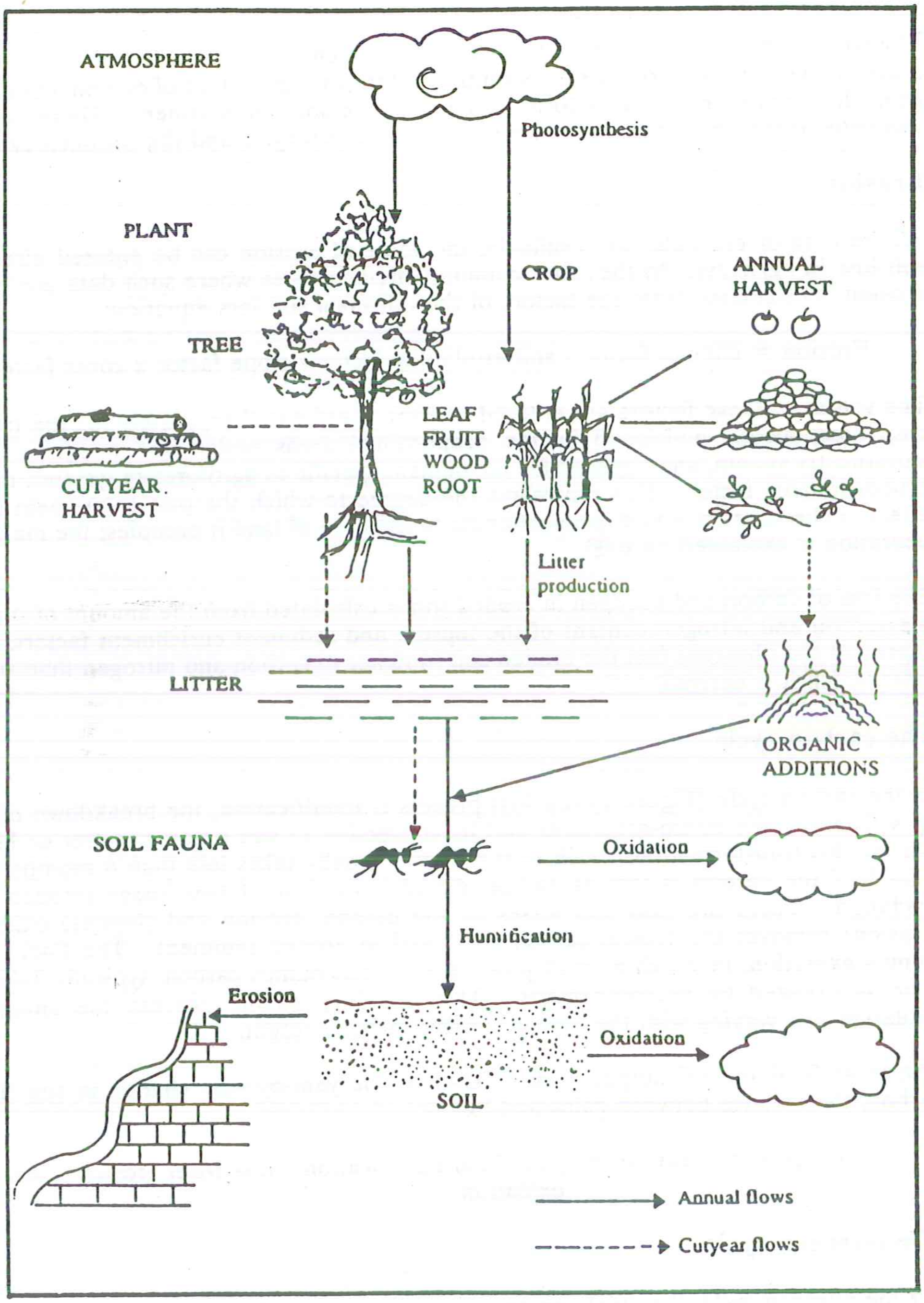

Figure 1. The SCUAF carbon cycle, simplified (Young, 1989).

The soil compartment

The soil compartment is that part of the model which calculates the changes which take place annually in soil properties. Outputs of litter, with its content of carbon and nitrogen from the plant compartments form an input to the soil compartment. There are three elements to the soil compartment: erosion, the carbon cycle and the nitrogen cycle.

Erosion

Where data or estimates are available, the value of erosion can be entered directly, as soil loss in kg/ha/yr. In the more common circumstances where such data are lacking, erosion is calculated from the factors of the universal soil loss equation:

Erosion = climate factor x soil erodibility factor x slope factor x cover factor.

The values of these factors are entered. Cover is estimated separately for the tree and crop components, multiplied by the proportional areas under tree and crop in the agroforestry system, and adjusted for an element specific to agroforestry systems, the tree proportionality factor. This represents the degree to which the tree component has an effect in checking erosion disproportionate to the area of land it occupies; the manner of operation is explained on p.00.

The loss of carbon and nitrogen in eroded soil is calculated from the amount of soil loss, the carbon and nitrogen content of the topsoil, and sediment enrichment factors, which represent the observed fact the eroded soil in richer in carbon and nitrogen than the soil from which it is derived.

The carbon cycle

In the carbon cycle (Figure 1) the first process is **humification**, the breakdown of litter by soil meso- and micro-organisms and its conversion to soil organic matter or humus. During this transformation, which in the tropics usually takes less than 6 months, more than half the carbon is lost as carbon dioxide, the first of two losses through litter **oxidation**. There are now two losses of soil carbon, erosion and (humus) oxidation. **Erosion** removes the topsoil carbon contained in eroded sediment. The final loss is **humus oxidation**, in which a small proportion of soil humus carbon, typically 3-4% per year, is oxidized by microorganisms. This is a homeostatic process, the amount of oxidation loss varying with the amount of soil carbon present.

The most fundamental output from SCUAF is the year-by-year change in soil humus carbon, the balance between gains and losses:

Change in soil carbon = gain from humification - loss from erosion - loss from oxidation

The nitrogen cycle

For the nitrogen cycle, the plant compartment is identical. The nitrogen contained in the eight plant parts is specified as the nitrogen content at the time at which each part leaves the plant compartment, as harvest or litter.

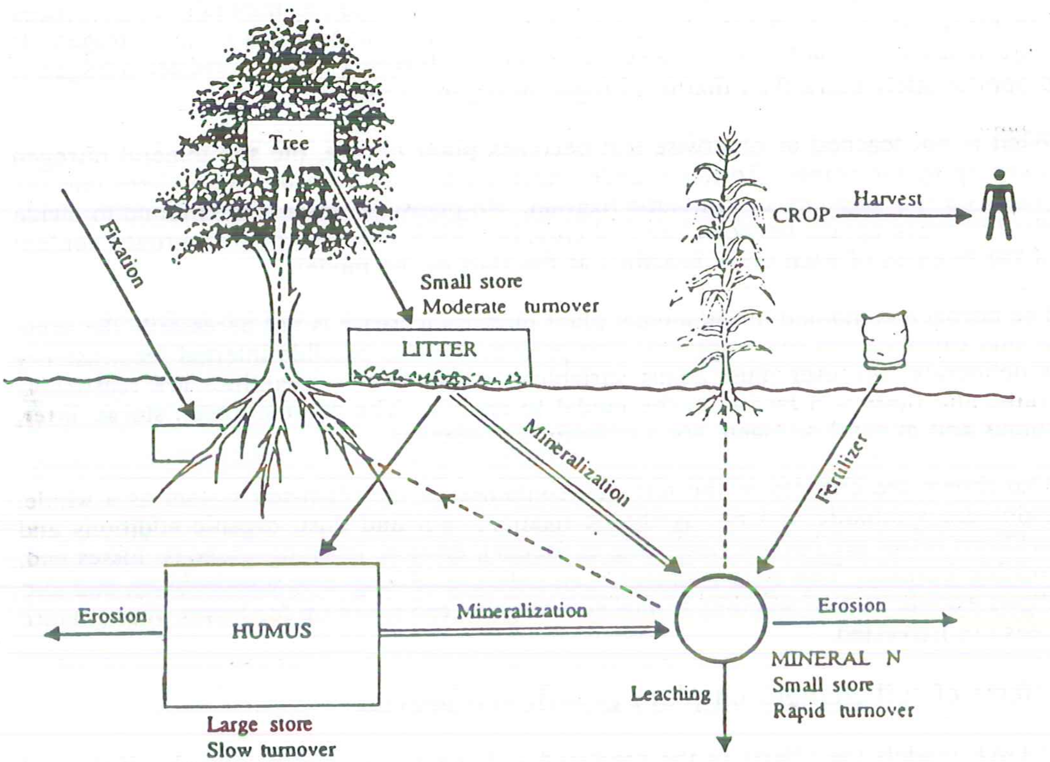

Figure 2. The SCUAF nitrogen cycle, simplified (Young, 1989).

The soil compartment is more complex for the nitrogen cycle (Figure 2). There are two stores of nitrogen in the soil, organic (as humus) and mineral, the latter much smaller than the former. Part of the litter nitrogen enters the soil humus, the amount so taken up being controlled by the litter carbon and the carbon:nitrogen ratio of the receiving store, the soil humus. Part of the humus nitrogen is transformed annually to mineral form, by **humus mineralization.** Changes in soil humus nitrogen occur in a way comparable to humus carbon: a gain from litter humification against which are set losses through erosion and mineralization.

The second balance modelled is that of soil mineral nitrogen (Figure 2). The size of this pool fluctuates seasonally, and at any one time it contains only something of the order of

1% of the nitrogen held in organic form. In SCUAF, the simplifying assumption is made that the mineral nitrogen pool is created and destroyed each year. Inputs to it come from **mineralization of litter**, **mineralization of humus**, (net) **non-symbiotic fixation**, **organic additions** (manure, etc.) and **inorganic additions**, as fertilizer. Having determined the size of the mineral nitrogen pool, specified fractions of this are lost through **leaching**, **gaseous losses** (denitrification and volatilization) and net **fixation** onto clay minerals. SCUAF does not distinguish, nor model the transformation, between ammonia and nitrate nitrogen. It does, however, allow for the observed fact that the leaching loss of fertilizer nitrogen is proportionately more than that of nitrogen of organic origin.

What is not leached or otherwise lost becomes **plant uptake**, the soil mineral nitrogen taken up by the plants. To this is added nitrogen passing from the atmosphere into the plants via root nodules, by **symbiotic fixation**. No plausible way could be found to divide plant nitrogen uptake between tree and crop, but this is indicated by the nitrogen content of the biomass of each cycle, specified at the start of the model.

The nitrogen contained in the annual plant biomass increase is not necessarily the same as that calculated as plant uptake! The presence of this possible internal inconsistency is deliberate; the user must adjust variables until these two quantities are reasonably equal, and there is a facility in the model to do this. The other nitrogen stores, litter, humus and mineral nitrogen, are automatically balanced.

Also shown are changes in the nitrogen contained in the plant-soil system as a whole. Gains are symbiotic and non-symbiotic fixation, rain and dust, organic additions and fertilizer; losses are harvest (including as fodder), erosion, leaching, gaseous losses and, possibly, burning. This system change is an indicator of long-term sustainability, and also allows examination of whether annual system gains can make up for losses when mature trees are harvested.

Effects of soil changes on plant growth and harvest

SCUAF models the effects of the predicted soil change upon plant growth. If the soil carbon, plant nitrogen uptake or soil profile depth decrease, plant growth is likely to become slower. If they increase, then will become faster. The magnitude of the effects of soil properties upon plant growth is specified by the user of the model.

Finally, the consequences of soil-induced changes in plant growth for harvest are calculated and displayed. There are the outputs both of the scientist's view of what constitutes sustainability, as changes in soil properties, and the farmer's view, as harvest.

Default values

In any given example, some of the values required for the model are likely to be missing. There may be data, for example, on above-ground plant growth but not on root production; often, the amount of nitrogen lost in leaching will not have been measured. To allow for this, SCUAF contains a set of default values. These are best estimates of all values in the model for the environmental conditions specified. Early in the input procedure, the user specifies the climate, soil and slope of the site. As soon as this is done, the model adopts a set of default values which are best estimates for this environment.

The SCUAF menu

A feature of SCUAF is the ability to change the value of one or a few variables and re-run a model, retaining all other values. This enables users rapidly to answer a series of questions of the form, 'What happens if I change XXX?' where XXX may refer to:

- a quantity (e.g. initial soil carbon);
- a rate (e.g. tree net primary production);
- a design feature (e.g. inter-hedgerow spacing);
- a management operation (e.g. harvest versus retention of tree prunings, or change in amount of fertilizer);
- a process (e.g. soil carbon decomposition constant, or rate of symbiotic nitrogen fixation).

This facility is achieved by making each group of inputs and outputs to the model function independently of all the others. Figure 3 is a diagrammatic view of the SCUAF menu. There are three sub-menus, for inputs, outputs and utilities. When starting a new model, the user selects the Input Menu and (normally) works through items 1-11. After that it is possible to obtain selected outputs in any order, or a complete set. The user can then:

- go to any item of inputs and change one or more values;
- return to any selected output and see what effect the change has had.

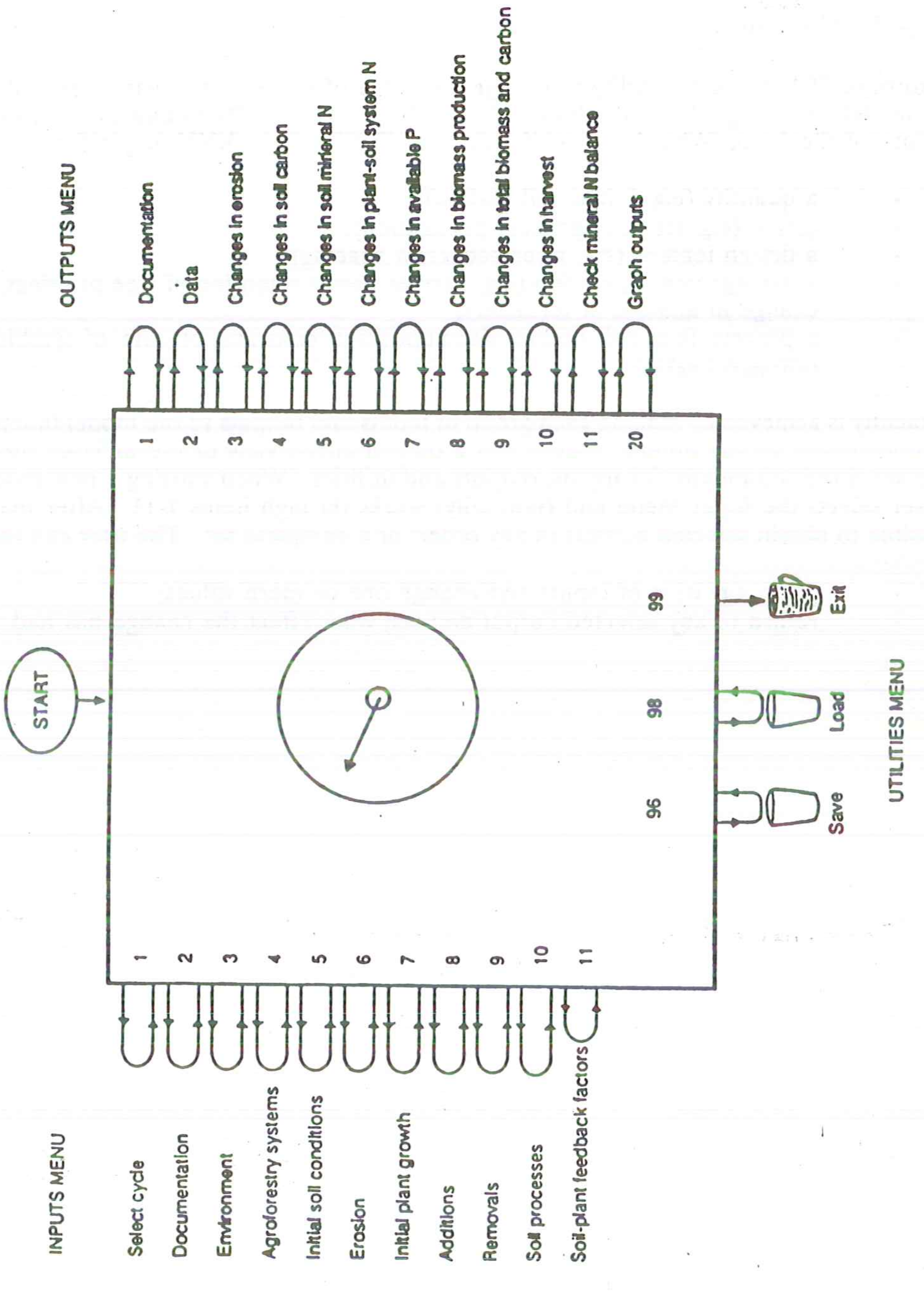

Figure 3. User's view of the SCUAF menu.

3 GETTING STARTED

The hardest part of starting to use any computer program is getting as far as the appearance of the first instruction on the screen! We hope the following is foolproof, but if you have difficulties, e.g. error messages, please write and report exactly what happens (running the computer's 'Printscreen' facility is often helpful).

> It is recommended that you first make a backup of the diskette on which SCUAF is supplied, to protect against loss.

Users with a hard disk

Installing SCUAF

We assume you have an IBM-compatible (MS-DOS, PC-DOS) computer with at least one diskette drive (see p.107 for further details). We shall call the hard disk **Drive C:** and the diskette **Drive A:**.

Start in the root directory of Drive C:, within the operating system. First, create a subdirectory SCUAF for storing the program, using the following command:

```
MD\SCUAF
```

Next, create two more subdirectories, SCUAF\MODEL for storing models and SCUAF\OUTPUT for storing outputs, using the following commands:

```
MD\SCUAF\MODEL
MD\SCUAF\OUTPUT
```

From the root directory, change to the SCUAF subdirectory using the command:

```
CD\SCUAF
```

The screen prompt will now usually be C:\SCUAF>. Place the diskette on which the program is supplied in Drive A:. Copy it into Drive C: subdirectory SCUAF using the command:

```
COPY A:*.*
```

This will copy 4 files into subdirectory SCUAF. By using the Directory command, DIR, you should obtain the following:

```
SCUAF20.   EXE
UPDATE.    EXE
USERPLOT.  EXE
AUTO123.   WK1
MODEL      <DIR>
OUTPUT     <DIR>
```

The supplied diskette may now be removed and stored safely.

After running the program for the first time, one more file will appear on the SCUAF subdirectory:

MODELS. CXT

If you have received a later Version of the model the executive file will have a different name, e.g., SCUAF21.EXE for Version 2.1.

The final step is to set up the automatic graph-plotting facility. To use this, it is necessary that the user possesses the **Lotus 1-2-3** program (for copyright reasons, ICRAF cannot supply this). To enable the SCUAF graph plotting facility to operate, first create a subdirectory LOTUS on Drive C by typing:

MD\LOTUS

Then copy Lotus 1-2-3 into this subdirectory.

Next, ensure that the default directory within LOTUS is C:\LOTUS. To do this, load LOTUS 1-2-3, obtain the starting menu by typing "/", and request successively, "Worksheet", "Global", "Default" and "Directory"; change the default directory to C:\LOTUS and press the Return key, followed by "Update" and "Quit". Finally, for technical reasons it is necessary that there should be at least one file with the extension .PRN in the Lotus subdirectory. Exit from LOTUS into the C:\LOTUS subdirectory, and copy **any file** into this--it does not matter what is in the file. Then change its extension to .PRN, e.g. DUMMYFIL.PRN.

Installation is now complete and the program may be loaded.

Loading SCUAF

Installing SCUAF only needs to be done once. Loading it, i.e. transferring the program from the disk into the computer memory, is done each time it is to be used.

To load SCUAF, first change to the subdirectory C:\SCUAF by typing the command:

CD\SCUAF

Then load the program by typing the command:

SCUAF20

(or SCUAF21 etc. for a later Version).

An introductory message will appear on the screen. After reading it, press the RETURN key.

The Main Menu will appear on the screen. Providing that it does, then both you, the user, and we, the originators, can breathe a sigh of relief: the steps most likely to give trouble are over! You are now ready to begin using SCUAF.

Users without a hard disk

Installing SCUAF.

We assume you have an IBM-compatible (MS-DOS, PC-DOS) computer, with two diskette drives (see p.107 for further details). We shall call these Drive A: and Drive B:.

Place the diskette on which the program is supplied in Drive A:. Place a blank formatted diskette (on which data will be stored) in Drive B:.

It is not essential, but is recommended, to divide the data diskette into two subdirectories, SCUAF\MODEL for storing models and SCUAF\OUTPUT for storing outputs. To do this, transfer the operating system to Drive B: and type the following commands:

```
MD SCUAF
MD SCUAF\MODEL
MD SCUAF\OUTPUT
```

Transfer the system to Drive A:. Using the Directory command, DIR, you should obtain the following:

```
SCUAF20.   EXE
UPDATE.    EXE
USERPLOT.  EXE
AUTO123.   WK1
```

Without a hard disk, it is not possible to use the automatic graph-plotting facility. Graphs can, however, still be obtained using your own software (p.108).

Loading SCUAF

To load SCUAF, first place the diskette with the SCUAF program in drive A:. Place a blank formatted diskette, to receive data, in drive B:. If necessary, change the default drive (screen prompt) to A:.

Load the program into the computer memory by typing the command:

```
SCUAF20
```

(or SCUAF21 etc. for a later Version).

An introductory message will appear on the screen. After reading it, press the RETURN key. The Main Menu will appear on the screen. You are now ready to begin using SCUAF.

4 USING SCUAF: AN INTRODUCTION

The aim of this chapter is to familiarize you with using SCUAF by means of some simplified examples. More detailed explanations will be found in the chapters below on Inputs and Outputs.

It is assumed that you have followed the instructions in Chapter 3 up to the point where the program is installed and loaded, and the Main Menu appears on the screen.

MODEL 1: SHIFTING CULTIVATION IN THE LOWLAND HUMID ZONE

Inputs

As the first example, let us take the oldest form of agroforestry, shifting cultivation, and an environment for which it is typical, the lowland humid or rain forest zone. This is a rotational agroforestry system, one in which the interaction between the tree and crop components takes place in time. It is widely accepted that with short periods of cultivation followed by long periods of fallow, this system maintains the soil in a steady state, soil degradation during the cropping period being balanced by restoration of fertility under the forest fallow. It is also well known that where population pressure enforces a shortening of the fallow period, soil degradation results. We shall model this on SCUAF using for the most part simulated data, the default values.

From the Main Menu, select 1 - Input Menu, by typing 1 and pressing the RETURN (or ENTER) key.

All inputs are followed by pressing the RETURN (or ENTER) key. This will no longer be stated.

When first starting a model, it is safest to work through Items 1-11 of the Input Menu in order. So press 1 to obtain the input, **Select Cycle.** This will ask whether you wish to consider choice 1, the carbon cycle alone, or choice 2, the carbon and nitrogen cycles combined. There is a screen statement:

Current Choice is [2]

Any value shown in square brackets is the **current value** of a variable; in this case, the variable 'Cycle' has the value 2, a coded value meaning 'Carbon and Nitrogen Cycles'. Values which first appear are also **default values**, that is, values which the model will use unless you enter different ones. To accept the current value as displayed, simply pass the RETURN key. This is what we want to do here.

This first input only contains one question, so on pressing return it is completed and the prompt appears:

SELECT FUNCTION (0 = MENU)

Press 0 (number zero, not capital O) and the Input Menu will again appear.

Now select 2 - **Input/Modify Documentation.** A file name is asked for. This can be up to 8 letters, or letters followed by numbers. As we are testing shifting cultivation, and this is the first model, type SHIFTCL1 (and press RETURN). Next we need a title. There is more space available here, so call it SHIFTING CULT. 1.

The remaining questions in this input are non-functional, other than as labels to identity the model and run it. Either skip them, by repeatedly pressing RETURN, or enter anything you like. The date, for example, can be entered as 11 AUGUST 1990, or 11.8.90, or 8.11.90.

Have you made a typing error? You cannot 'go back', upward through the questions. Simply obtain the Input Menu and select 2 - Documentation again. Your error will appear in square brackets as the current value, say SHFCL1, and you can change it by entering the correct value.

From the Input Menu, now select 3 - **Input/Modify Environment**. The function of the physical environment inputs is to set the default values (p.10). After that, they play no further part in the functioning of the model.

Our shifting cultivation system is in the lowland humid zone so the Current Climate shown is wrong. Enter 1 to replace it. The words 'Lowland Subhumid' will remain, but if you re-enter this input, they will have changed to 'Lowland Humid'.

Now let us accept the default settings for all other environmental variables: a medium-textured soil, with free drainage and acid reaction, on a gentle slope. If you like, select Input 3 again (you do not have to return to the Input Menu) to make sure the current value of climate is now Lowland Humid.

Input 4 - **Agroforestry System** is where we can begin to enter the detailed features for the model. For the first run, we will assume that there are 2 years of annual cropping and 8 years of forest fallow, in the last of which the forest is felled and burnt. This is described in SCUAF by a series of Periods. For reasons explained below, we must begin with a forest fallow. We shall need not 2 but 3 periods:

7 years of forest
1 year of forest, felled
2 years of cultivation

Under Input 4, the prompt, 'Period 1: Length in years' appears. This is not the (arbitrary) default value of 5 but is 7 years long, so change and enter it. There is a complete forest cover so change 'Fraction of land under tree' to 1.0 (1.0 or 1. or 1 will be accepted), and 'Fraction of land under crop' to 0 (zero). The next question asks what fraction of the tree component is nitrogen-fixing. For rain forest, the answer is rather low, so enter 0.05. There is no crop in this period, so the question about nitrogen-fixation is irrelevant.

'Any more periods?' Yes, there are, so change N to Y for "Yes". Period 2 is one year long and is again 100% trees (entered as 1.0) and no crops. Because it is only 1 year, the further question appears, 'Is it a cutyear?'. A cutyear is a year in which the tree component is cut in some way (p.6), so enter Y for 'Yes'. Answers on nitrogen fixation are the same as for Period 1. There is one more period, 'Y(es)'.

(Did you let the default 'No' slip through by mistake? Select Input 4 again, and keep pressing RETURN until you reach the same point.)

Now there is one more period, that of cultivation: 2 years long, 0.0 under trees, 1.0 under crops. Let us assume the cropping is maize monoculture, so the nitrogen-fixing fraction of the crop component is 0.0.

There is no need to enter a fourth period for return of the fallow. Under SCUAF, Period 1 automatically returns after the last period specified. So allow N = 'No' to stand and return to the Input Menu.

(Do you feel like a break? Are you worried you will lose your data? At any time during the inputs you can **save** the model, and subsequently **reload** it, by following the instructions on p.19.)

To save time on this first test example, we will cover the remaining inputs more quickly, accepting the default values except where they need changing to meet the circumstances of this example.

Select Input 5 - **Initial Soil Conditions**, and press RETURN in reply to the three questions about soil depth. At the question, 'Initial carbon, Topsoil (percent)', **change the default value** shown as [2.000] **to 1.15**. Then press RETURN to accept all other values. You will see that initial soil carbon has been calculated as 29 900, this being the result of: Soil depth considered x initial carbon (percent) x bulk density x 1000 = initial soil carbon, or

$$20 \times 1.15 \times 1.3 \times 1000 = 29\,900$$

By default, a carbon:nitrogen ratio of 10:1 has been assumed, giving topsoil nitrogen of 0.115%. As exceptions to the general rule in SCUAF that proportions are given as fractions, topsoil carbon and nitrogen are entered as percentages, because this is the unit used in soil analytical data.

Now do the same for Input 6 - **Erosion**, accepting all default values. Default values for the factors of erosion appear, typical for a gentle slope and medium-textured soil under a lowland humid climate. Cover factors are given for the tree and crop components. These factors are used to calculate 'Soil erosion under tree (kg/ha/yr)' and under crop, that is, with 100% of the area under trees and under crops respectively. You may like to check the calculation, using the equation shown at the top. These rates are 630 kg/ha/yr under a forest cover, and 42 000 kg/ha/yr (42 tonnes) under a cereal crop. As this is a rotational agroforestry system, the tree proportionality factor (p.58) does not apply. The enrichment factors at the end of the input are a measure of how much higher are the proportions of carbon and nitrogen in the eroded sediment as compared with the topsoil from which it has been derived. By default these are set at twice as high, a common experimental finding.

Input 7 - **Plant growth** is also fundamental to the model. Trees that grow faster produce more litter; crops that are higher yielding remove more nitrogen in harvest. The net primary production (NPP) of the tree component, 20 000 kg DM/ha/yr, is typical for rain forest. That for the crop, however, is rather high for a shifting cultivation system, so **reduce it to 6000 kg DM/ha/yr.** Accept the default values for roots as a fraction of above-ground NPP, 0.4 or 40%. Next, you are asked the NPP in the different plant parts. Forest regrowth probably has a higher proportion of wood to leaf than is given by the default values, so **reduce tree leaf to 3400** and **raise tree wood to 16 200 kg DM/ha/yr.** Accept the other default values. This is a long input, so now accept all remaining default values. Do not worry at this stage about the meaning and significance of all the questions, but note the section on plant material 'retained as growth', that is, entering the standing biomass. The tree leaf and fruit are cast off annually, but 0.9 (90%) of the NPP of woody matter is retained in the growing tree (the value of 0.67 for roots is a guess, as there are few data). The crop is an annual, so nothing is retained as growth.

Input 8 - **Additions** covers organic additions and fertilizer brought into the land-use system. In shifting cultivation there are none, which is the default assumption.

Input 9 - **Removals** is again critical to the results of the model. It specifies which parts of the tree and crop components are harvested or otherwise removed. What remains, enters the soil. The first two sets of questions cover the **annual harvest** of the tree and crop. The whole of crop fruit is harvested, so the default value of 1.0 is retained. We will assume crop residues are not harvested, so the default value of 0.0 is correct. The next questions cover the cutyear harvest. One of the defaults needs to be altered; in shifting cultivation the tree wood is not harvested, so **alter 1.0 to 0.0**. There are, however, 'other losses from the system', namely burning during the cutyear, so **answer Yes to this question**. Nothing is burnt annually, so accept the 8 zero values; but in the cutyear, most of the tree biomass, including its carbon and nitrogen, is lost. Studies show that some plant matter usually survives the burn, so enter the 'additional fraction of Tree lost in cutyear' as:

Leaf	1.0
Fruit	1.0
Wood	0.9
Root	0.0

There are no losses of crops so accept the zero values.

Now accept the default values for the whole of Input 10 - **Soil Processes**. This gives typical values, for a freely drained medium-textured soil under a lowland climate, for various processes in the carbon and nitrogen cycles. By default, you are making the assumption of **one humus fraction**, as suggested on p.61.

Finally, accept the default values in Input 11 - **Plant/soil Feedback Factors**. This completes the input of data.

Note that even if you are accepting all the default values, **you must go through inputs 5, 6, 7 and 9**, pressing the RETURN key, otherwise some internally calculated values (initially set to 'signal' levels of -1) will not be calculated.

Saving and reloading a model

To avoid the chance of losing the data, save this model before going any further, as follows:

1. Enter 99 to exit from the Input Menu.
2. Enter 3 to select the **Utilities Menu**.
3. Enter 1 - **Save a current model**.

The file name SHIFTCL1 will appear. Do not alter it but press RETURN. The model will be saved. If you wish you can now enter 99 twice, exit from SCUAF, and leave or switch off the computer.

When you wish to continue, or resume, work on this example, **reload** the model as follows:

1. From the Main Menu, enter 3 to select the **Utilities Menu.**
2. Enter 2 - Load a model.
3. Type in this file name of the model, SHIFTCL1, and press RETURN. (If you make a mistake, a list of available models will appear.)
4. Enter 99 to return to the Main Menu.

Checking the data

Now we shall examine the data for the shifting cultivation example. If, but only if, you have entered values exactly as suggested above, your results should correspond to those given in the following account.

From the Main Menu choose 2 - **Output Menu** and select 1 - **Display Documentation.** What was typed in under Input 1, Documentation, will appear on the screen.

Table 1. Model 1: Documentation.

FILE NAME: SHIFTCL1
TITLE: SHIFTING CULT. 1
SOURCE: SCUAF USER'S MANUAL
COUNTRY:
LOCATION:
CYCLE: CARBON AND NITROGEN
NOTES:
ASSUMPTIONS FOR OUTPUT:
DATE OF INPUT: 11 AUGUST 1990
DATE OF OUTPUT: 11 AUGUST 1990

Let us print this. Switch on the line printer, then hold down the CONTROL key and press P (written as CONTROL + P). Now select Output 1 again. The Documentation will be printed. This should look like Table 1.

Switch off the printer output by CONTROL + P again, and return to the Output Menu by pressing 2. The next output, 2 - **Display Data,** is better directed to the printer as it scrolls off the screen. Switch on the printer output (CONTROL + P again) and select 2 - **Display Data.** The complete set of data will be printed. This should look like Table 2.

NOW GO AWAY FROM THE COMPUTER AND CAREFULLY CHECK ALL THE DATA FROM YOUR PRINTOUT.

It is strongly recommended that you do this every time a new model is started, before proceeding with outputs. You have just entered 156 values and it would be surprising if there were not some errors. First, correct these by hand on the printout, then proceed by the following steps:

1. If necessary, go to the Utilities Menu and **reload** the model.
2. Go to the Input Menu. Select only those inputs in which there are corrections, and make these.
3. Go to the Utilities Menu and **save** the corrected model. It will overwrite the file saved previously.

Outputs

Having entered, checked and corrected the data, you are ready to proceed with the outputs proper. As was done with the inputs, we will do this quickly for this example. Detailed explanations of all outputs are given beginning on p.85.

If, when checking the data, you switched of the computer (or someone else used it for another purpose), then resume by the following steps:

1. Load SCUAF, and obtain the Main Menu.
2. Select the Utilities Menu, option 2 - Load a Model, and enter SHIFTCL1.
3. Proceed via the Main Menu to the Output Menu.
4. Select Output 1 - Documentation, to confirm that this model has been loaded.

It is suggested that you obtain outputs on the screen first and then, if they look satisfactory, direct them to the printer (by pressing CONTROL + P). Begin by printing again Output 1 - Documentation, as a heading or identification to the outputs which follow.

For this first example, we will discuss only selected outputs. Begin with Output 3 - **Agroforestry system**, by going to the Output Menu and typing 3. You are now asked, 'For how many years?'. Enter 12, which will enable you to inspect one complete cycle of forest fallow and cultivation, plus the beginning of the next fallow. A table will appear, headed **Agroforestry system** (Table 3).

Table 2. Model 1: Data.

FILE NAME=	SHIFTCL1
TITLE=	SHIFTING CULT. 1

Physical Environment

CLIMATE=	Lowland humid
TEXTURE=	Medium texture
DRAINAGE=	Free
REACTION=	Acid
SLOPE=	Gentle

Agroforestry System

PERIOD	YEARS	AREA UNDER TREE	AREA UNDER CROP	CUTYEAR
1	7	1.0	0.0	N
2	1	1.0	0.0	Y
3	2	0.0	1.0	N

Soil Conditions

TOPSOIL DEPTH (cm)=	20.00
SOIL DEPTH CONSIDERED (cm)=	20.00
TOTAL SOIL DEPTH (cm)=	200.
INITIAL CARBON, TOPSOIL (percent)=	1.150
INITIAL CARBON, SUBSOIL (percent)=	0.500
BULK DENSITY, TOPSOIL (g/cc)=	1.300
BULK DENSITY, SUBSOIL (g/cc)=	1.500
INITIAL SOIL CARBON (kg/ha)=	29900.
INITIAL N, TOPSOIL (percent)=	0.115
INITIAL TOPSOIL C:N RATIO=	10.00
INITIAL SOIL N (kg/ha)=	2990.

Erosion

RAINFALL FACTOR=	1000.00
SOIL ERODIBILITY FACTOR=	0.30
SLOPE FACTOR=	0.35
TREE COVER FACTOR=	0.006
CROP COVER FACTOR=	0.400
TREE PROPORTIONALITY FACTOR=	0.800
SOIL EROSION, YEAR 1 (kg/ha/yr)=	630.
CARBON ENRICHMENT FACTOR, ERODED SEDIMENT=	2.00
NITROGEN ENRICHMENT FACTOR, ERODED SEDIMENT=	2.00

Plant Growth

TREE, NET PRIMARY PRODUCTION (kg DM/ha/yr)=		20000.	
CROP, NET PRIMARY PRODUCTION (kg DM/ha/yr)=		6000.	
ROOTS AS A FRACTION OF ABOVE GROUND NPP:		TREE	CROP
		0.40	0.40
NPP OF PLANT PARTS	PART	TREE	CROP
	Leaf	3400.	4000.
	Fruit	400.	2000.
	Wood	16200.	0.
	Root	8000.	2400.

Table 2 (continued).

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

CARBON FRACTION RETAINED AS GROWTH ANNUALLY

PART	TREE	CROP
Leaf	0.00	0.00
Fruit	0.00	0.00
Wood	0.90	0.00
Root	0.67	0.00

CARBON FRACTION RETAINED AS 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

CARBON FRACTION RETAINED AS 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 GROWING BELOW SOIL DEPTH CONSIDERED

PART	TREE	CROP
Root	0.40	0.20

Additions

ORGANIC ADDITIONS:	
PERIOD 1	0.
PERIOD 2	0.
PERIOD 3	0.
CARBON AS FRACTION OF ORGANIC ADDITIONS=	0.50
CARBON:NITROGEN RATIO IN ORGANIC ADDITIONS=	25.
INORGANIC ADDITIONS:	
FERTILIZER (kg/ha/yr):	0.
PERIOD 1	0.
PERIOD 2	0.
PERIOD 3	0.
NITROGEN FRACTION IN FERTILIZER=	0.20

Removals

FRACTIONS HARVESTED 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 HARVESTED 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

Table 2 (continued).

FRACTIONS LOST OTHER THAN IN HARVEST ANNUALLY

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

FRACTIONS LOST OTHER THAN IN HARVEST AT CUTYEAR

PART	TREE	CROP
Leaf	1.00	0.00
Fruit	1.00	0.00
Wood	0.90	0.00
Root	0.00	0.00

Soil/plant processes

Carbon Cycle

LITTER-TO-HUMUS CONVERSION LOSSES:

ABOVE GROUND PLANT RESIDUES=	0.85
ROOTS=	0.67
ORGANIC ADDITIONS=	0.67

NUMBER OF HUMUS FRACTIONS CONSIDERED= 1

FRACTION OF COARSE ROOTS DECAYING > =1 YEAR LATER:

TREE	CROP
1.00	0.00

FRACTION OF REMAINING ROOTS DECAYING 2 YEARS LATER:

TREE	CROP
0.25	0.00

HUMUS DECOMPOSITION CONSTANTS:
LABILE HUMUS:

K UNDER TREE=	0.030
K UNDER CROP=	0.040
K UNDER SYSTEM (YEAR 1)=	0.030

Nitrogen Cycle

FRACTION OF TREE THAT IS N-FIXING:

	TREE	CROP
PERIOD 1	0.05	0.00
PERIOD 2	0.05	0.00
PERIOD 3	0.05	0.00

INITIAL TOPSOIL NITROGEN (percent)=	0.11
INITIAL TOPSOIL C:N RATIO=	10.00
INITIAL SOIL NITROGEN (kg/ha)=	2990.
NITROGEN ENRICHMENT FACTOR, ERODED SEDIMENT=	2.00

NITROGEN FRACTION IN DRY MASS OF:

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

FERTILIZER NITROGEN (kg/ha/yr):

PERIOD 1	0.
PERIOD 2	0.
PERIOD 3	0.

Table 2 (continued).

NITROGEN GAINS		
SYMBIOTIC FIXATION		
- PER UNIT AREA OF N-FIXING TREE (kg/ha/yr) =	100.	
- PER UNIT AREA OF N-FIXING CROP (kg/ha/yr) =	100.	
- PER UNIT AREA OF SYSTEM (kg/ha/yr) =	5.	
FRACTION OF SYMBIOTIC FIXATION ENTERING SOIL HUMUS =	0.1.	
NON-SYMBIOTIC FIXATION (kg/ha/yr) =	8.00	
FRACTION OF NON-SYMBIOTIC FIXATION ENTERING SOIL HUMUS =	0.0	
ATMOSPHERIC INPUTS (RAIN, DUST) (kg/ha/yr) =	12.00	
THOUGHFALL AND STEMFLOW (kg/ha/yr) =	10.00	
NITROGEN LOSSES		
A. MINERAL N OF ORGANIC ORIGIN:		
FRACTION OF MINERAL N LEACHED UNDER TREE =	0.05	
FRACTION OF MINERAL N LEACHED UNDER CROP =	0.20	
FRACTION OF MINERAL N LEACHED UNDER SYSTEM (YEAR 1) =	0.05	
FRACTION OF MINERAL N LOST		
- BY GASEOUS LOSSES =	0.05	
- BY FIXATION ONTO CLAY MINERALS =	0.00	
B. FERTILIZER N:		
FRACTION OF FERTILIZER N LEACHED UNDER TREE =	0.10	
FRACTION OF FERTILIZER N LEACHED UNDER CROP =	0.40	
FRACTION OF FERTILIZER N LEACHED UNDER SYSTEM (YEAR 1) =	0.10	
FRACTION OF FERTILIZER N LOST:		
- BY GASEOUS LOSSES =	0.10	
- BY FIXATION ONTO CLAY MINERALS =	0.00	
Feedback Factors		
	TREE	CROP
CARBON/GROWTH =	0.25	0.50
NITROGEN/GROWTH =	0.25	0.50
DEPTH/GROWTH =	0.50	1.00

Table 3. Model 1: Agroforestry system.

TIME	AREA UNDER TREE	CROP	CUTYEAR
1	1.00	0.00	N
2	1.00	0.00	N
3	1.00	0.00	N
4	1.00	0.00	N
5	1.00	0.00	N
6	1.00	0.00	N
7	1.00	0.00	N
8	1.00	0.00	Y
9	0.00	1.00	N
10	0.00	1.00	N
11	1.00	0.00	N
12	1.00	0.00	N

The first column, Time, is common to all outputs, giving the time in years. The next two columns give the areas under trees and crops respectively, whilst the last column states whether it is a cutyear (p.6), as Y = Yes and N = No. This is simply a setting out, year by year, of the details of the agroforestry system that were entered under Input 4.

Type 0 to return to the Output Menu. Next, choose Output 5 - **Soil Carbon**, since this is the key to the behaviour of the SCUAF model as a whole. In response to the prompt asking for how many years, enter 12. The table, **Changes in soil carbon**, will appear (Table 4).The first column again gives the time, in years. There is an extra row, 'Initial', since the output for Year 1 gives the soil carbon at the **end** of that year. The second column, 'Total', gives the soil carbon, in kg C/ha. During the first 7 years the soil carbon falls slightly, but rises in Year 8, the cutyear, to 31 488 kg C/ha, slightly above its initial value; this is due to the decay of roots, dying back as the forest is felled and burnt. Soil carbon then falls in Years 9 and 10, the first cultivation period; the fall is slight in Year 9, owing to delayed inputs of decaying roots from the cutyear, but carbon drops more sharply in Year 10.

The remaining columns show how these changes in soil carbon have come about. Gains come from humification of plant residues: above-ground litter and root residues. The column 'Additions' refers to organic additions from outside, in this case zero. Carbon losses are from oxidation and erosion. Oxidation is the loss of soil humus by bacterial oxidation, at rates set by the decomposition constant. Erosion is loss of soil carbon in eroded soil. You may like to check the arithmetic of soil carbon changes: for Year 1, 29 900 + 668 + 0 - 897 - 14 = 29 656, and similarly for succeeding years. The output tabulated for Year 1 gives processes that occur **during** Year 1 and the state of the system at the **end** of Year 1.

Let us examine a second fallow-cultivation cycle. Press 0 for the Output Menu, select 5 again, and ask for 20 years. Soil carbon recovers to 31 783 in Year 18, falling to 30 575 during the second period of cultivation, Years 19 and 20. Examining the remaining columns shows the causes:

- oxidation is at a higher rate under cultivation than fallow;
- erosion is much higher during the two-year periods of cultivation;
- humification is boosted in the cutyear, and the two years following, by the dieback of root residues into the soil.

Table 4. Model 1. Soil carbon.

5 CHANGES IN SOIL CARBON

TIME	TOTAL	GAINS HUMIFICN	ADDITIONS	LOSSES OXIDATION	EROSION
Init	29900				
0	29656.	668.	0.	897.	14.
1	29419.	666.	0.	890.	14.
2	29187.	665.	0.	883.	14.
3	28960.	663.	0.	876.	14.
4	28737.	661.	0.	869.	14.
5	28520.	659.	0.	862.	14.
6	28307.	657.	0.	856.	14.
7	31488.	4045.	0.	849.	14.
8	31482.	2044.	0.	1260.	791.
9	30305.	1056.	0.	1259.	973.
10	30021.	640.	0.	909.	15.
11	29772.	666.	0.	901.	15.
12	29531.	667.	0.	893.	14.
13	29296.	665.	0.	886.	14.
14	29066.	663.	0.	879.	14.
15	28840.	661.	0.	872.	14.
16	28619.	659.	0.	865.	14.
17	31783.	4036.	0.	859.	14.
18	31762.	2044.	0.	1271.	793.
19	30574.	1058.	0.	1270.	975.

Return to the Output Menu and request 4 - **Changes in erosion**, for 16 years (Table 5). Column 7 gives the rate of soil erosion in kg/ha/yr. It is high during the cropping periods, low under forest fallow. The next two columns give the loss of C(arbon) and N(itrogen) in eroded soil. The severe erosion in Year 9, the first year of cropping, 32 649 kg (32.6 tonnes) of soil, carries away 791 kg of carbon and 79 kg of nitrogen. The last column, soil depth, shows that 1 cm of soil (or, rather, 0.5 cm, as it is rounded up) was lost during the first cultivation period.

Next, try Output 12 - **Harvest**, for 20 years (Table 6). Only one product is harvested, the crop fruit, with a yield of 2537 kg/ha in the first year of cultivation, falling to 2061 kg/ha in the second. Crop yields in the second period of cultivation are almost the same as in the first.

Finally, let us examine one of the four outputs for the nitrogen cycle. Select 8 - **Soil mineral nitrogen**, and ask for 12 years. Column 6, **Total avail.**, shows the available soil mineral nitrogen in each year. This is created by the Gains shown in Columns 2-5: mineralization of litter (including roots), mineralization of soil humus, constant (which covers inputs as rainfall, throughfall and stemflow) and additions (fertilizer, in this case zero). The total available mineral nitrogen remains nearly constant during Years 1-7 but is boosted by decay of tree roots in Year 8. It is also greater in Years 9-10 because the

Table 5. Model 1: Erosion.

4 CHANGES IN EROSION

TIME	CLIMAT FACTOR	SOIL FACTOR	SLOPE COVER	TREE COVER	CROP COVER	SOIL EROSN	C EROSN	N EROSN	SOIL DEPTH
Init	1000	0.30	0.35	0.006	0.400				
1	1000.	0.30	0.35	0.006	0.400	630.	14.	1.	200.
2	1000.	0.30	0.35	0.006	0.402	633.	14.	1.	200.
3	1000.	0.30	0.35	0.006	0.403	635.	14.	1.	200.
4	1000.	0.30	0.35	0.006	0.406	639.	14.	1.	200.
5	1000.	0.30	0.35	0.006	0.409	642.	14.	1.	200.
6	1000.	0.30	0.35	0.006	0.411	645.	14.	1.	200.
7	1000.	0.30	0.35	0.006	0.414	649.	14.	1.	200.
8	1000.	0.30	0.35	0.006	0.416	652.	14.	1.	200.
9	1000.	0.30	0.35	0.005	0.315	32651.	791.	79.	200.
10	1000.	0.30	0.35	0.006	0.388	40184.	973.	97.	200.
11	1000.	0.30	0.35	0.006	0.437	655.	15.	2.	199.
12	1000.	0.30	0.35	0.006	0.402	631.	15.	1.	199.
13	1000.	0.30	0.35	0.006	0.401	631.	14.	1.	199.
14	1000.	0.30	0.35	0.006	0.403	635.	14.	1.	199.
15	1000.	0.30	0.35	0.006	0.406	638.	14.	1.	199.
16	1000.	0.30	0.35	0.006	0.409	641.	14.	1.	199.

Table 6. Model 1: Harvest.

12 CHANGES IN HARVEST

	TREE			CROP	
TIME	LEAF	FRUIT	WOOD	LEAF	FRUIT
1	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	2537.
10	0.	0.	0.	0.	2061.
11	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	2548.
20	0.	0.	0.	0.	2070.

humus decomposition constant is higher under cultivation than under fallow. Columns 7-8 show leaching and other losses; leaching is higher under cultivation than forest, owing to nutrient retrieval by tree roots. What is not lost is taken up from the soil by plants (Column 9), to which is added the amount entering the plants directly through symbiotic fixation, small in this example (Column 10). This gives the total nitrogen supply to the plants, shown in the last column. At the start of the second fallow period, Year 11, it is almost identical, 166 kg N/ha/yr, to the start of the first fallow.

All of these outputs, for changes in soil carbon, rate of erosion, nitrogen uptake and plant growth, show that conditions remain fairly constant from one fallow-cultivation cycle to the next. With the input data used, and 8 years of fallow to every 2 of cultivation, this is a sustainable land- use system.

Graphing the outputs

If you possess the Lotus software package, and have correctly followed the installation instructions on p.14, you can rapidly inspect these tabular outputs converted to graphs.

From the Output Menu, select 20 - **Graph outputs**. If all goes well, a box will appear on the screen, 'Select the required job', and below it your title, SHIFTING CULT. 1. If more than one such title appears, move the highlight to this model using the up-down arrow keys and select it by pressing RETURN. All the outputs you have obtained will be listed. Select **Soil carbon, 1 fraction** in the same way.

Now you are asked to select the Y-variables (the X variable is time in years). The most interesting are **Total Carbon** and **Humification.** Move the highlight with the arrow keys and select both of these by pressing RETURN. To exit from this box, press function key F10.

Select a **line graph** and automatic scaling, and press RETURN. If all goes well, a graph, with title, subtitle, scales and legends, will appear on the screen (Figure 4). Total soil carbon, the upper line, falls slowly during the fallow period (contrary to 'textbook' expectations!) but rises sharply in the cutyear, due to the input of root residues (shown by the lower line, humification), then falls in the cropping period. In the long term, this system is stable.

To finish with a graph, press any key. Then, in response to the prompt, enter S to return to the Output Menu.

It must be said that this is the sort of place in which a program, run for the first time on a new computer, can go wrong! If, regrettably, this happens:

1. Check the installation instructions (p. 14).
2. Call in your local computer expert.
3. Failing that, write to ICRAF.

If all has gone well, however, try making graphs for your other outputs, **erosion, soil mineral nitrogen** and **harvest**. For **erosion**, first select Output 4 - **Erosion**, and obtain a tabular output, this time for 24 years, to give two fallow-cultivation cycles and the start of a third. Now make a graph of this, plotting just one variable, **soil erosion** (remember, the F10 key exits from this choice), and choose a line graph (Figure 5). You will see how erosion rises from the first to the second year of each cultivation period, but in this sustainable system it remains the same each time the cultivation period returns.

In the case of soil mineral nitrogen, choose three variables: **total available N** and its two main origins, **litter mineralization** and **humus mineralization**. Choose a line graph, and

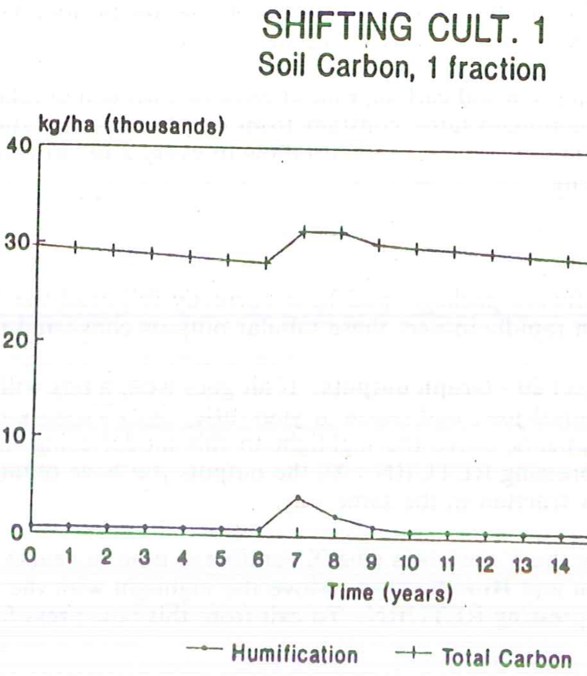

Figure 4. Model 1: soil carbon.

this time try manual scale limits: in response to the prompts, enter the lower scale limit as 0 and the upper limit as 300. The graph displays the cyclic fluctuations in nitrogen availability, but also its long-term steady state.

For harvest, a bar graph gives a good impression, graphing crop fruit with the upper scale limit set to 3000.

A note on Lotus 1-2-3

The SCUAF graph-plotting procedure creates a file AUTO123.WK1 on the LOTUS subdirectory. In order to use Lotus subsequently for other purposes, you must erase this file from the LOTUS subdirectory. To do this, type:

CD\LOTUS	Changes to Lotus subdirectory
ERASE AUTO123.WK1	Erases file

Do not erase AUTO123.WK1 from the SCUAF subdirectory.

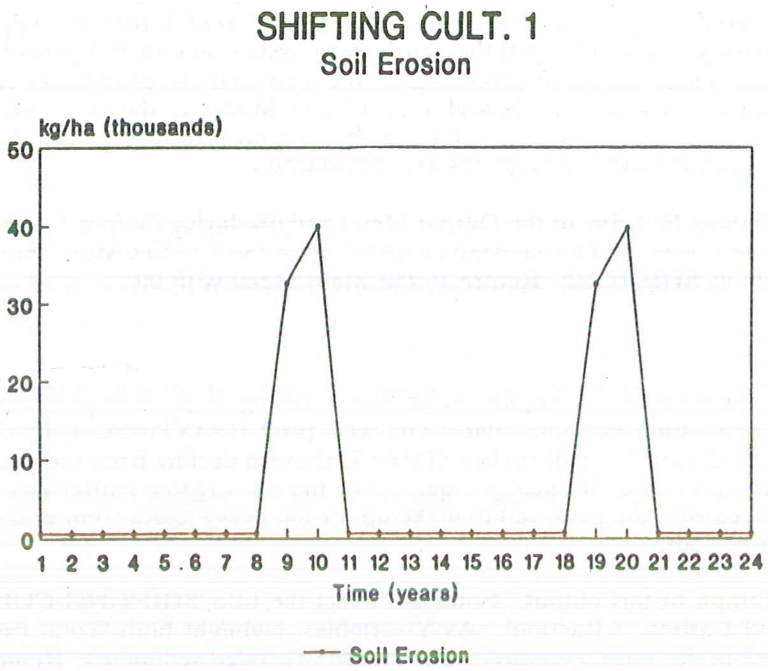

Figure 5. Model 1: erosion.

MODEL 2: SHIFTING CULTIVATION WITH REDUCED FALLOW PERIOD

The next example is to illustrate how it is possible to alter one variable and see what effect this has on the outputs. We shall simulate a change which often occurs in shifting cultivation, the increase in the ratio of cultivation to fallow periods. If the model entered as Model 1 is not already in the computer memory, load it by going from the Main Menu to the Utilities Menu, selecting 2 - **Load a Model**, and entering SHIFTCL1. Type 99 to return to the Main Menu, and 1 to proceed to the Input Menu.

Inputs

Before changing the critical input, the lengths of cultivation and fallow periods, you must first alter the file name and title. Unless this is done, outputs from Model 2 will be overwritten onto those from Model 1. On the Input Menu, select 2 - **Documentation**, and make the following changes:

File Name:	SHIFTCL2
Title:	SHIFTING CULT. 2
Notes:	AS MODEL 1, BUT WITH INCREASED CULTIVATION:FALLOW RATIO

Now go to Input 4 - **Agroforestry System**. 'Period 1' is the fallow period. You are going to reduce its length from 7 to 3 years, but the last of these is the cutyear, so **set Period 1 to 2 years**. Leave the other values for Period 1 unchanged. Leave Period 2, in which the forest is cleared, unchanged. **Increase the length of Period 3**, that of cropping, from **2 to 3 years**. Now you have changed the agroforestry system to one of 3 years fallow and 3 years cropping. The R factor, or percentage of the total land-use cycle under cultivation, has been increased from 20% in Model 1 to 50% in Model 2; this is a very common change in shifting cultivation systems, and one that is known to lead to soil degradation if no other changes in land-use practices are introduced.

Check these changes by going to the Output Menu and displaying Output 3 - **Agroforestry System**. Then exit from the Output Menu with 99, go to the Utilities Menu, and save this second example as SHIFTCL2. Return to the Main Menu with 99.

Outputs

Let us inspect the same three outputs as for Run 1, taking 16 years in each case. Select the Output Menu. First examine, and if you wish print (CONTROL + P) Output 1 - **Documentation**. Output 5 - **Soil carbon** (Table 7) shows a decline from the initial 29 900 to 22 785 kg C/ha in Year 16; nearly a quarter of the soil organic matter has been lost. Looking at the reasons, the gains fail to make up for the heavy losses from erosion during the cultivation periods.

Try making a graph of this output. Enter 20, select the title 'SHIFTING CULT. 2' and the output 'Soil Carbon, 1 fraction'. As Y-variables, highlight both 'Total carbon' and 'Erosion' (which in this output means loss of carbon in eroded sediment). Remember the exit here is function key F10. Choose a line graph, and either automatic scaling or a manual setting of 0 - 40 000. The progressive degradation of soil carbon is apparent (Figure 6).

Exit from the graph by pressing any key, followed by S. Then select 4 - **Erosion** and obtain a 16-year output (Table 8). Either from the tabular output or, more clearly, by making a graph, notice that:

i. The rate of soil erosion increases from the first to the third year of each cultivation period, e.g. in Years 4-6 from 37 941 to 51 329 kg/ha/yr.
ii. Rates of erosion increase with the return of each successive cultivation period.

Both these effects are caused, first, by the reduced soil resistance to erosion caused by impoverishment in organic matter, and, second by the reduced cover factors resulting from poorer plant growth (a higher value for a factor of erosion means more erosion). Output 8 - **Soil mineral nitrogen**, shows that the nitrogen supply also decreases from one cycle to the next, another cause of reduced plant growth.

Lastly, select Output 12 - **Harvest** and note, from the table or by obtaining a bar graph of crop fruit, the two forms of decline: during each 3-year cultivation period, and from one such period to another.

Why could these examples not be started with a cutyear or a period of cultivation? Because SCUAF would not know about the accumulated biomass of tree roots in the forest fallow.

Table 7. Model 2: Documentation and Soil carbon. When commencing the printed output of a new model, it is good practice always to begin with the Documentation, as an identification.

DOCUMENTATION

FILE NAME: SHIFTCL2
TITLE: SHIFTING CULT. 2
SOURCE: SCUAF USER'S MANUAL
COUNTRY:
LOCATION:
CYLCE: CARBON AND NITROGEN
NOTES: AS MODEL 1, BUT WITH INCREASED CULTIVATION:FALLOW RATIO
ASSUMPTIONS FOR OUTPUT:
DATE OF INPUT: 11 AUGUST 1990
DATE OF OUTPUT: 11 AUGUST 1990

5 CHANGES IN SOIL CARBON

TIME	TOTAL	GAINS HUMIFICN	ADDITIONS	LOSSES OXIDATION	EROSION
Init	29900				
1	29656.	668.	0.	897.	14.
2	29419.	666.	0.	890.	14.
3	30467.	1946.	0.	883.	14.
4	29515.	1156.	0.	1219.	889.
5	27989.	715.	0.	1181.	1061.
6	26277.	513.	0.	1120.	1105.
7	26065.	591.	0.	788.	15.
8	25896.	627.	0.	782.	14.
9	26919.	1813.	0.	777.	14.
10	25990.	1050.	0.	1077.	903.
11	24516.	644.	0.	1040.	1078.
12	22877.	458.	0.	981.	1117.
13	22737.	560.	0.	686.	14.
14	22637.	596.	0.	682.	13.
15	23667.	1722.	0.	679.	13.
16	22785.	969.	0.	947.	904.

Saving the model

Save the data for Model 2, with the file name SHIFTCL2, by following the instructions given under 'Saving and reloading a model' on p. 19.

To introduce SCUAF, we have used it to model a well-known phenomenon: that in shifting cultivation systems a reduction in the ratio of fallow to cropping periods, unaccompanied by other changes in land-use practices, leads to a soil-degrading, non-sustainable system.

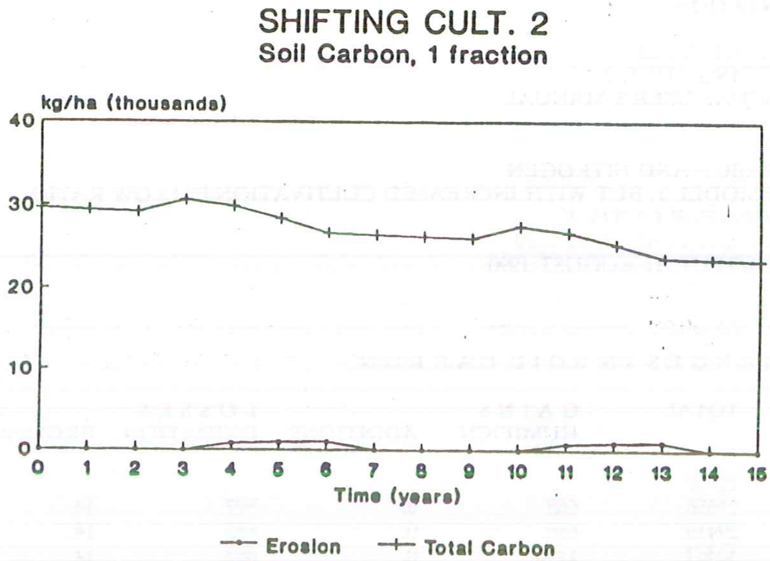

Figure 6. Model 2: soil carbon.

MODEL 3: HEDGEROW INTERCROPPING IN THE HIGHLAND SUBHUMID ZONE

For the next example, let us take one of the most common agroforestry technologies that is a subject of current research, hedgerow intercropping (also called alley cropping). One of the main reasons for the attention given to hedgerow intercropping is its apparent potential to control soil erosion and maintain fertility. It is also a land-use system in which there are a large number of variables, such as tree (hedgerow) species, hedgerow width, inter-hedgerow spacing, pruning regime, fertilizer and many other management practices. SCUAF can be used to explore the effects of changes in these variables, e.g. what would happen if inter-hedgerow spacing were wider, or if hedge prunings were removed for fodder instead of being retained on the soil.

The following example is very loosely based on data in a published research report, because many simplifying assumptions have been made although the source is not identified. The hedgerows are pigeon pea (*Cajanus cajan*) and the crop is maize.

Table 8. Model 2: Erosion.

4 CHANGES IN EROSION

TIME	CLIMAT FACTOR	SOIL FACTOR	SLOPE FACTOR	TREE COVER	CROP COVER	SOIL EROSN	C EROSN	N EROSN	SOIL DEPTH
Init	1000.	0.30	0.35	0.006	0.400				200.
1	1000.	0.30	0.35	0.006	0.400	630.	14.	1.	200.
2	1000.	0.30	0.35	0.006	0.402	633.	14.	1.	200.
3	1000.	0.30	0.35	0.006	0.403	635.	14.	1.	200.
4	1000.	0.30	0.35	0.006	0.363	37942.	889.	89.	200.
5	1000.	0.30	0.35	0.006	0.444	46733.	1061.	106.	200.
6	1000.	0.31	0.35	0.007	0.481	51329.	1105.	109.	199.
7	1000.	0.31	0.35	0.007	0.516	735.	15.	1.	199.
8	1000.	0.31	0.35	0.006	0.454	693.	14.	1.	199.
9	1000.	0.31	0.35	0.006	0.451	692.	14.	1.	199.
10	1000.	0.31	0.35	0.006	0.405	43600.	903.	89.	199.
11	1000.	0.31	0.35	0.007	0.496	53934.	1078.	106.	199.
12	1000.	0.31	0.35	0.007	0.538	59213.	1117.	109.	198.
13	1000.	0.32	0.35	0.007	0.579	798.	14.	1.	198.
14	1000.	0.32	0.35	0.007	0.506	751.	13.	1.	198.
15	1000.	0.32	0.35	0.007	0.501	748.	13.	1.	198.
16	1000.	0.32	0.35	0.006	0.448	49652.	904.	89.	198.

Clearing the current model

In entering Model 2 above, you loaded Model 1 and changed a few selected values. Now, for Model 3, you wish to enter an entirely new set of data. If this is being done during a new session, i.e. immediately after loading SCUAF, it can be done right away. However, if you have been running one model, e.g. Model 2, it is first necessary to clear all the current values and reset SCUAF to its initial values. To do this:

- Make sure that you have saved Model 2 (p. 19).
- Go to the Main Menu.
- Select the Utilities Menu.
- Select 4 - **Clear current model.**

Nothing will appear to happen, except a repeat of the request SELECT FUNCTION. In fact, however, during that fraction of a second, all the current values have been cleared, and reset to their initial values. To return to the Main Menu, enter 99. You may check this by calling any of the inputs; for example, under Input 2 - **Documentation**, the file name will have been reset to FILENAME.

It is essential to clear the current model if you wish to start a new model in the same computer session (i.e. without exiting and reloading). If you simply over-write the old values with the new, without clearing, various internal calculations will not be done.

Inputs

If you are continuing a computer session, then first clear the current model.

If you are starting a new session then, using the same instructions as those given for Model 1, Run 1:

- enter the SCUAF subdirectory;
- type SCUAF to load it;
- press RETURN to take the Introduction off the screen;
- from the Main Menu, type 1 to select the Input Menu.

Proceed through the Input Menu in sequence from 1 to 11. There are two ways to go from one item to another. At the end of each item you can type 0, which brings the Input Menu back onto the screen, and then type the required number. Alternatively, you can obtain a printout of the Input Menu (using the PRINTSCREEN or CONTROL + P function), keep it for reference, and at the end of one input item, go directly to the next by typing its number.

Input 1 - **Select Cycle**

The default selection is Carbon and Nitrogen Cycles, which is what we require, so press the RETURN key.

Input 2 - **Documentation**

Enter the File name HEDGINT1 and the Title HEDGEROW INT. 1. Enter the Source as this handbook and the Country as RURITANIA. The Location, Notes and Assumptions for output may be left blank by pressing the RETURN key. Enter today's date for Input date.

Input 3 - **Environment**

Climate:	Highland subhumid
Soil texture:	Medium textured
Drainage:	Free
Reaction:	Acid
Slope:	Gentle

Enter the above data by typing the number corresponding to the environmental class, as shown by the screen prompts. For climate, alter the default value (lowland subhumid) to highland subhumid by typing 5. The remaining classes are the same as the default classes, so leave these by pressing RETURN.

Input 4 - **Agroforestry System**

We will consider a purely spatial hedgerow intercropping system, with no element of rotation. Thus only one Period is needed; it does not matter how many years this is said to be, because when the last specified period is finished, the first Period returns. In this case the 'first' and 'last' Periods are the same, so leave the default value of 5 years (or enter 1, 10, 20 or 50 years, it makes no difference).

In this system, hedgerows alternate with cropped alleys. The hedgerows are either straight and parallel or, on sloping land, set out along contours and thus sub-parallel. The relative proportions of hedgerows and alley are recognized as one of the most critical features of design. They can be varied by making the hedgerow wider (e.g. 2 lines of shrubs) or making the alleys wider (by planting the hedgerows further apart).

The relative proportions under hedgerow and cropped alley are referred to in SCUAF as **Area under tree** and **Area under crop** respectively. They are expressed as fractions, e.g. 10% under hedge is expressed as Area under tree = 0.1.

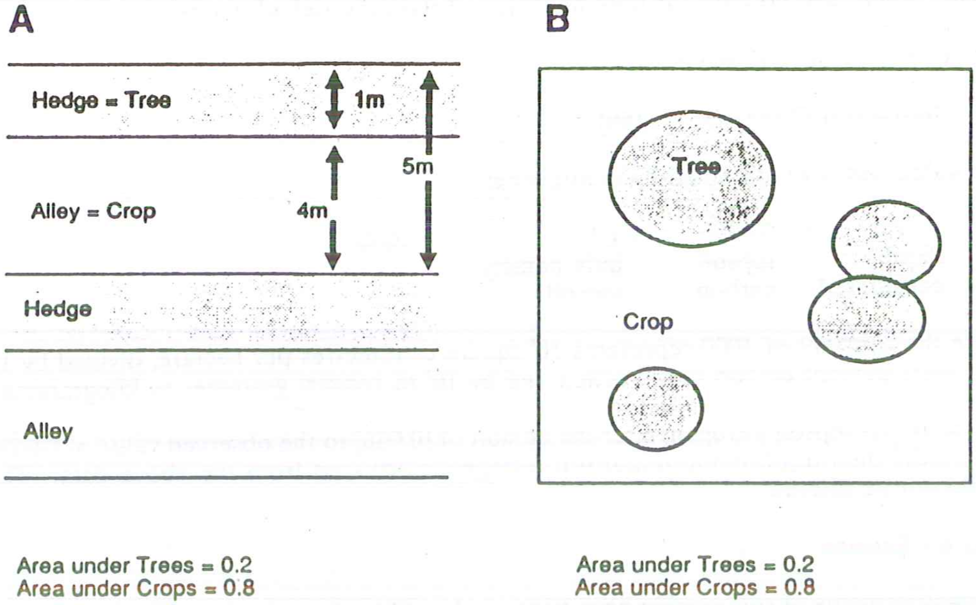

Figure 7. Model 3: areas under tree and crop components.

Assume the hedgerow width is 1.0 m and the alley width 4.0 m (Figure 7). The inter-hedgerow spacing, or total width of one hedge-plus-alley unit, is thus 5.0 m. This gives:

Area under tree = 1.0/5.0 = 0.2
Area under crop = 4.0/5.0 = 0.8

In this example, the tree is *Cajanus cajan* (pigeon pea) and the crop is maize. The tree component is therefore entirely nitrogen-fixing and the crop component is not. Enter these as fractions 1.0 and 0.0 respectively. If the crop were, for example, a rotation of maize and beans, or a 50-50% intercrop of maize and beans, the Fraction of crop that is nitrogen-fixing would be 0.5. There is no rotation, so answer 'N' to 'Any more periods?'

Input 5 - Soil

Data for the topsoil (0-20 cm) are:

Organic carbon	0.66%
Nitrogen	0.06%

Retain the default values for Topsoil depth, Soil depth considered and (because of lack of data), Total soil depth. For Initial carbon, topsoil, change the default value to 0.66%.

The value for the subsoil does not matter as you are only considering changes to the upper 20 cm. There are no data for bulk density, so retain the default values.

The screen will now display:

Initial soil C (kg/ha) [17160]

This value has been obtained by multiplying:

20 cm depth considered	x	0.66% topsoil carbon	x	1.3 bulk density topsoil	x	1000

where the constant of 1000 represents 10^8 square centimetres per hectare, divided by 10^2 to convert percent carbon to a fraction and by 10^3 to convert grammes to kilogrammes.

For the initial topsoil nitrogen, alter the default of [0.066] to the observed value of 0.06%. The model then displays the initial soil nitrogen, calculated from the above data. This should not be altered.

Input 6 - Erosion

No measurements of soil erosion have been made, although general observation suggests that on this site it is not substantial. The slope is very gentle. Therefore accept all the default data except the slope factor, which in view of the description 'very gentle' (rather than the default 'gentle') is reduced from 0.35 to 0.2. Using the universal soil loss equation, coupled with the tree proportionality factor (p.58), the model calculates soil erosion as 2506 kg/ha/yr, or 2.5 tonnes. This is well below the value of 10 t/ha/yr commonly regarded as acceptable.

Input 7 - Plant growth

The rate of plant growth, or net primary production (NPP) is one of the critical inputs to SCUAF. Changes in plant growth will substantially affect the outputs. This is also an input for which data are normally available.

Based on dry-matter weights from prunings, and from the complete shrubs when removed at the end of the experiment, data are:

Plant growth for the experimental plot

	TREE	CROP
Above-ground NPP	2450	3500
Leaf	1020	2220
Fruit	801	280
Wood	13	500

These data, however, are obtained from a spatial system in which trees occupy 0.2 of the total land area and crops 0.8. Such biomass data are system-dependent, and would change if the proportion of trees and crops were altered. SCUAF makes use of a more fundamental value, the hypothetical biomass production if the total land area were covered by one component, tree or crop respectively. (It is hypothetical because it may not be the same as the observed biomass production on plots totally covered by one component, for a variety of reasons). To obtain the values for plant growth required by SCUAF, the observed yields must be divided by the fractional areas under each component: the tree yields by 0.2 and crop yields by 0.8. This gives the following derived data:

Plant growth required for SCUAF inputs

	TREE	CROP
Above-ground NPP	12250	4375
Leaf	5100	2775
Fruit	400	1600
Wood	6750	0

It is essential to understand the principle that has been followed in the input of plant growth, and how to apply it. **In spatial agroforestry systems, the measured plant growth from each component (tree and crop) of a system is divided by the proportional area under that component,** to give a hypothetical plant growth from and area of land entirely under each component.

Enter these data in response to the opening prompts of the input. There are no data on roots, so retain the default value of 0.4. Using the above-ground net primary production, the root growth is calculated as tree 4900 and crop 1750 kg DM/ha/yr.

The questions on fractions retained as growth refer to how much of the annual growth increment remains in the standing plant the following year. For pigeon pea this is rather small, so alter the default value for tree wood from 0.9 to 0.1. Reduce the fraction of tree roots that are coarse roots (meaning their decay takes more than one year) to 0.2, on grounds of general knowledge of the plant rather than specific data, and the fraction of tree roots growing below soil depth considered (20 cm) to 0.33. Accept the default values for carbon fractions and for nitrogen fractions in plant parts.

Input 8 - Additions

There are no Organic additions, so enter 0. Their carbon fraction and carbon:nitrogen ratios become irrelevant, so can be left. We will assume that 100 kg/ha/yr of a 40% nitrogen fertilizer is applied, so enter 100 and 0.4 in response to the prompts. SCUAF then calculates a fertilizer nitrogen input of 40 kg N/ha/yr.

Input 9 - Removals

This is another critical input: removal of a plant part (e.g. crop residues, tree leaf prunings), as opposed to retaining it as litter on the soil, substantially affects soil changes.

In this system the crop fruit, maize cobs, and the tree fruit, pigeon peas, are both harvested, but the crop residues are not. Alter the default value for tree fruit from 0 to 1.0, and leave the other default values. There are no losses other than harvest. (Note that, because there is no cutyear specified in the agroforestry system, the question about additional harvest in the cutyear is not asked.)

Input 10 - **Soil/plant processes**

This set of inputs lies within the area of specialist soil studies, and data are unlikely to be available from normal agroforestry experiments. The functioning of the carbon and nitrogen cycles, as used in SCUAF, is explained in outline in Chapter 2 and in more detail in Chapter 5. The default values are obtained from published specialized studies. They are best estimates for the environmental conditions specified in Input 3, for the climatic zone (rates of carbon oxidation, natural nitrogen inputs and nitrogen leaching), soil texture (fractions of litter carbon lost, rate of leaching) and drainage (rate of leaching).

Let us therefore retain these values, with one exception--if only to show that they can be changed if wished! The default value for symbiotic nitrogen fixation per unit area of nitrogen-fixing tree, 100 kg N/ha/yr, is rather high for pigeon pea, so alter this to 80.

Input 11 - **Feedback factors**

Feedback factors represent the effects of changes in soil carbon, nitrogen and depth upon plant growth. Their manner of functioning is explained on p. 66. There are no data on which to base estimates for this model, so retain the default values.

Checking the data

It is important at this point to save the data, print them, and check them. Instructions on how to do so are given for Model 1 above (p.19-21). In outline, the steps are:

- Go to the Utilities Menu and Save the model.
- Go to the Output Menu, set the output to the printer and obtain printouts of Outputs 1 - Documentation and 2 - Data.
- Go away from the computer and carefully check the data.
- Where necessary, go to the Input Menu and correct the data.

Outputs

In Model 1 above we looked at selected outputs only. For Model 2 we shall consider all of the outputs, although some in outline only. For a full account of the meaning of each output, see Chapter 6.

Outputs 1 and 2, Documentation and Data, have been considered above, in the process of checking the data.

The system under consideration, permanent hedgerow intercropping, is purely spatial; there are no cutyears and no element of rotation. In such cases, an output of 5 years is sufficient to show the direction, or trend, of soil changes: whether the soil is degrading, in a nearly steady state or improving. A longer run, say for 10 or 20 years, will indicate the magnitude of changes, for example whether soil erosion is likely to reach unacceptable levels. In a purely spatial system, however, it is not possible for a trend, once established, to become reversed. We shall discuss the outputs for 5-year periods.

Output 3 - **Agroforestry system**

This is extremely simple for a purely spatial system: there is only one Period, in every year of which the tree component covers 0.2 of the land area and the crop component 0.8 (20% and 80% respectively).

Output 4 - **Changes in erosion**

In Year 1 soil erosion, shown in Column 7, is calculated as 2506 kg/ha/yr. This is the result of multiplying the causative factors and allowing for the effect of the tree proportionality factor. It is a relatively low value, well below the limit regarded as acceptable. The losses of carbon and nitrogen in eroded sediment (Columns 8 and 9) are also low, 33 and 3 kg/ha/yr respectively.

Over time, the rate of erosion very slightly decreases, to 2489 kg/ha in Year 5. This is the result of a decrease in the crop cover factor (Column 6), caused by improved growth (see below). Better plant growth, and thus more soil cover, means a lower cover factor. Soil depth (Column 10) remains virtually constant; if you repeat the output for a longer period, you should find that it is not until Year 32 that the printed depth falls to 199 cm, showing loss of 0.5 cm of soil (i.e. depth has fallen below 199.5 cm).

The change in total soil depth is used as the basis for the depth feedback effect on plant growth--in this example, extremely small.

Carbon cycle outputs

Output 5 - **Changes in soil carbon**

The total soil carbon, shown in Column 2, rises slowly in this system, from the initial 17160 to 17319 kg C/ha in Year 5. The gain from humification of plant litter, 555 kg/ha/yr in Year 1, exceeds the losses from oxidation and erosion, 489 and 33 kg/ha/yr respectively. Additions (Column 4) refer to organic additions, which are zero in this system.

The gain in soil carbon is a key element in the SCUAF model. Provided that it is observed, trends in all other soil and plant variables are likely to be positive. In the research on which this example is loosely based, an increase in topsoil carbon was observed (the increase was much larger than that modelled, but its statistical basis was not given). From a soil point of view, this agroforestry system is sustainable.

The change in soil carbon is used as the basis for the carbon feedback effect on plant growth.

Output 6 - **Changes in total biomass and carbon** (Table 9)

Columns 2-4 show the Current plant biomass, that is, the biomass of the standing plant at the end of the year, after litter fall and harvest. It is obtained from the fractions of plant parts stated to be 'Retained as growth' in Input 7. For the tree component, this consists of parts of the wood and roots. Because the crop is an annual, values for it are zero. The hedgerows of pigeon pea gradually build up their standing biomass year by year, trunks and main roots becoming thicker.

Table 9. Model 3: Documentation, Total biomass and carbon.

DOCUMENTATION

FILE NAME: HEDGINT1
TITLE: HEDGEROW INT. 1
SOURCE: USER'S HANDBOOK
COUNTRY: RURITANIA
LOCATION:
CYCLE: CARBON AND NITROGEN
NOTES:
ASSUMPTIONS FOR OUTPUT:
DATE OF INPUT: 8.12.89
DATE OF OUTPUT: 8.12.89

6 CHANGES IN TOTAL BIOMASS AND CARBON

T	CURRENT PLANT BIOMASS TREE	CROP	PLANT-SOIL SYSTEM CARBON TOTAL	PLANT	SOIL	TOTAL
1	792.	0.	792.	396.	17193.	17588.
2	1584.	0.	1584.	792.	17225.	18016.
3	2376.	0.	2376.	1188.	17256.	18444.
4	3169.	0.	3169.	1585.	17288.	18872.
5	3963.	0.	3963.	1982.	17319.	19301.

Columns 5-7 show the trend in total carbon within the plant-soil system. The value for plants is derived from the current plant biomass, that for the soil being a repeat of the soil carbon in Output 5. The rising total implies that more carbon is being brought into this system by photosynthesis than is being lost by oxidation.

Nitrogen cycle outputs

There are four outputs for the nitrogen cycle, representing the four subsystems shown in Figure 15 (p.65).

Output 7 - **Changes in soil organic nitrogen (Table 10)**

This is the nitrogen-cycle equivalent of Output 5 for soil carbon, showing the nitrogen held in organic form within the soil humus. In this model it increases, from 1560 kg N/ha initially to 1602 at the end of Year 5. The gains are primarily from humification of plant litter, with a small element of fixed nitrogen specified as entering the soil humus (rather than the plant). The losses are mainly through conversion to mineral nitrogen, with a little erosion. With respect to nitrogen as well as carbon, this system is sustainable.

Table 10. Model 3: Soil organic nitrogen.

7 CHANGES IN SOIL ORGANIC NITROGEN

TIME	TOTAL	GAINS FIXATION	HUMIFICN	ADDITIONS	LOSSES MINERALZN	EROSION	C:N RATIO
Init	1560						11.0
1	1569.	2.	50.	0.	40.	3.	11.0
2	1577.	2.	51.	0.	41.	3.	10.9
3	1585.	2.	51.	0.	41.	3.	10.9
4	1594.	2.	51.	0.	41.	3.	10.8
5	1602.	2.	51.	0.	42.	3.	10.8

Table 11. Model 3: Soil mineral nitrogen.

8 CHANGES IN SOIL MINERAL NITROGEN

T	GAINS LITTER MINER.	HUMUS MINER.	CONS-TANT	ADDI-TIONS	TOTAL AVAIL.	LOSSES LEAC-HING	OTHER LOSSES	PLANT UPTAKE	SYMB. FIXN	SUM TO PLANTS
1	24.	40.	15.	40.	120.	14.	8.	98.	14.	113.
2	24.	41.	15.	40.	120.	14.	8.	98.	14.	113.
3	24.	41.	15.	40.	120.	14.	8.	99.	14.	113.
4	24.	41.	15.	40.	120.	14.	8.	99.	14.	113.
5	24.	42.	15.	40.	121.	14.	8.	99.	14.	113.

Output 8 - Changes in soil mineral nitrogen (Table 11)

SCUAF assumes that the pool of soil mineral nitrogen is created, and utilized, afresh each year. Columns 2-5 show the gains to this mineral nitrogen pool. In Year 1, 24 kg N are mineralized directly from decaying plant litter, and 40 kg from soil humus. Column 4, Constant, is the sum of inputs as rain and dust, fixation, and throughfall and stemflow. Additions (Column 5) is the sum of nitrogen in organic additions, in this example zero, and that added as fertilizer, 40 kg. This gives a pool of available mineral nitrogen (Column 6) of 120 kg N/ha.

The next two columns, headed Losses, cover loss of this pool other than by plant uptake. Column 7 shows leaching, combining leaching of nitrogen of organic origin with that of fertilizer origin. Column 8, Other losses, is the sum of losses through erosion, denitrification and volatilization. In this system, these losses are quite small, leaving 98 kg N/ha for plant uptake (Column 9). To this is added 14 kg N/ha entering plant roots directly from symbiotic fixation, to give a total nitrogen supply to the plants (last column) of 113 kg N/ha/yr. SCUAF does not partition the nitrogen uptake between the tree and crop.

Over the first 5 years, the nitrogen uptake appears to remain exactly constant, although a longer output shows is to be very slowly increasing. (The apparent indication that 98 + 14 and 99 + 14 both equal 113 is a rounding effect.)

The last column, showing the total mineral nitrogen taken up by the plants, is the basis for the nitrogen feedback effects on plant growth.

Table 12. Model 3: Plant-soil system nitrogen.

9 CHANGES IN PLANT-SOIL SYSTEM NITROGEN

T	GAINS CONS-TANT	SYMB. FIXN	ADDI-TIONS	TOTAL GAINS	LOSSES HAR-VEST	BURN ETC.	EROS-ION	LEAC-HING	GAS-EOUS	TOTAL LOSS	NET GAIN/LOSS
1	10.	16.	40.	66.	34.	0.	3.	14.	8.	59.	7.
2	10.	16.	40.	66.	34.	0.	3.	14.	8.	59.	7.
3	10.	16.	40.	66.	34.	0.	3.	14.	8.	59.	7.
4	10.	16.	40.	66.	34.	0.	3.	14.	8.	59.	7
5	10.	16.	40.	66.	34.	0.	3.	14.	8.	59.	7.

Output 9 - Changes in plant-soil system nitrogen (Table 12)

Output 9 compares nitrogen flows into and out of the total plant-soil system, comprising plants, soil organic matter and soil mineral nitrogen. Most headings are self-explanatory:

Gains: Constant: rainfall and dust, plus non-symbiotic fixation.
Symbiotic fixation: in this system, by the tree only.
Additions: in this system, from fertilizer.
Total gains: the sum of the above.

Losses: Harvest: nitrogen removed in harvested plant parts, the maize cob and pigeon peas.
Leaching: of mineral nitrogen, as in Output 8.
Gaseous: denitrification and volatilization.
Total losses: the sum of the above.

The last column shows net change, the gains minus the losses, shown with a minus sign if there is a net loss. In this system there is a net gain of 7 kg N/ha/yr to the system. Input as in fertilizer exceeds removal in harvest, whilst other system gains slightly outweigh leaching and other losses.

Output 10 - **Mineral nitrogen balance check**

The meaning of this output is explained on p.91. Basically, it is a check on whether the assumptions and data entered into the model are internally consistent. The measurement of plant growth rates, multiplied by the nitrogen content of plant parts, indicates that 125 kg nitrogen are contained in the plant biomass increment. The mineral nitrogen balance, as shown in the last column of Output 8, gives an estimate that 113 kg nitrogen has been taken up by the plants. In effect,12 kg nitrogen has been 'created', unaccounted for by the model. Given the many unknown factors in the nitrogen cycle, this is a reasonably good result. Possibly the nitrogen content of plant parts is some 10% less than estimated, or leaching losses are lower. The screen prompts indicate various ways of changing the inputs so as to produce a better balance.

Table 13. Model 3: Plant growth (as affected by soil).

11 CHANGES IN PLANT GROWTH (as affected by soil)

T	TREE LEAF	FRUIT	WOOD	ROOT	TOTAL	CROP LEAF	FRUIT	WOOD	ROOT	TOTAL	TREE+ CROP
1	1020.	80.	1350.	980.	3430.	2220.	1280.	0.	1400.	4900.	8330.
2	1020.	80.	1351.	980.	3431.	2222.	1281.	0.	1401.	4904.	8336.
3	1021.	80.	1352.	981.	3434.	2225.	1283.	0.	1403.	4911.	8345.
4	1022.	80.	1353.	982.	3437.	2229.	1285.	0.	1406.	4919.	8356.
5	1023.	80.	1354.	983.	3440.	2233.	1287.	0.	1408.	4928.	8368.

Plant growth outputs

Output 11 - **Changes in plant Biomass production (as affected by soil)** (Table 13).

In Output 11, the qualification 'as affected by soil' is important. This output shows only the estimated effects of soil changes upon plant growth, not the many other factors that can affect such growth--soil water, weeds, pests, etc.

The basis for this estimate is the feedback factors, coupled with the changes in soil carbon, nitrogen and profile depth. The way in which these are combined is explained on p.84. In the present model, both soil carbon and nitrogen uptake are slowly increasing, giving a positive effect on plant growth. Soil depth is decreasing but very slowly indeed, by 0.5 cm in 32 years, 0.016 cm/yr, or 0.008 percent of its original depth of 200 cm, so its effect is negligible. Growth of the crop increases proportionately more than that of the tree, the result of using the default values for feedback factors in which the crop is assumed to be more sensitive to soil changes. Within each plant, changes to all parts are the same.

Output 12 - **Changes in harvest**

This is simply a reproduction of those columns from Output 11 that are stated to be harvested. In this case it shows the tree fruit, pigeon peas, and the crop fruit, maize cobs. It was stated in the inputs that neither wood from the tree nor crop residues were harvested.

Graphical outputs

All of the above outputs 3-9, 11 and 12 can be obtained as graphs by naming Output Menu selection 20. The way to obtain a graph, by following the screen prompts, is given for Model 1 (p.29). In the present example, all of the graphs are very uninteresting, being very slowly rising, virtually straight lines.

MODEL 4: MAIZE MONOCULTURE

Now let us compare the above system of hedgerow intercropping with one of maize monoculture. For real experimental data, we could use values obtained from a control plot. In the present case, we shall make use of the facility in SCUAF to alter one or a few variables, leaving all others constant. In particular, we shall assume that the maize yield, per unit area of land under maize, is initially the same in the monoculture as in the intercropping system.

Initial steps

- Load SCUAF.
- Select the Utilities Menu.
- Select 2 - Load a model.
- Replace FILENAME with HEDGINT1, the file name of Model 3; press the RETURN key.
- Type 99 to return to the Main Menu.

All the variables now have the values of Model 3.

Inputs

Input 1, Select cycle, is left unchanged, retaining the combined carbon and nitrogen cycles.

Input 2 - **Documentation**

First, change the file name and title, so that when the run is modified, it is stored separately. Change the file name to MAIZE1 the title to MAIZE MONOCULTURE 1. Then under Notes, type COMPARISON WITH HEDGINT1, ALL OTHER VALUES SAME.

Input 3 - **Environment** is left unchanged.

Input 4 - **Agroforestry system**

It is here that we shall make the one, critical, change that distinguishes Model 4 from Model 3. The values currently displayed are those loaded from Model 3, namely a hedgerow intercropping system with fractional areas of 0.2 under the tree component and 0.8 under the crop. To change this to maize monoculture, replace these values with 0.0 under tree and 1.0 under crop.

Nothing else need be changed! By not even calling Inputs 5-11 we ensure that all values within them are the same as they were for the hedgerow intercropping system. If we were using real data from a control plot, then the maize yield would be different, and this would be entered as crop net primary production in Input 7 - **Plant growth**. But in this example, we wish to see what is the effect on the soil of not having a hedgerow component, even if the crop yield is the same.

Save the data

Exit from the Input Menu, and select the Utilities Menu. Choose 1 - **Save a model, and** save MAIZE1.

Outputs

Exit from the Utilities Menu and enter the Output Menu. Select 1 - **Documentation**, and the new headings and notes for Model 3 should appear on the screen, with the file name MAIZE1.

Now press CONTROL+P to direct output to the printer, and select 1 - **Documentation** again, so that it is printed, as a heading to subsequent outputs. If you wish, print Output

2 - **Data** as well, although it should be the same as for run 1 in every detail except Areas under tree and crop. To remove output from the printer, press CONTROL+P again.

Subsequent outputs may now be obtained on the screen alone or screen+printer, as you wish. As with Run 1, a 5-year period is sufficient to indicate the direction of trends. This time, we will examine the outputs briefly and selectively.

Output 4 - **Changes in erosion** shows that erosion in Year 1 is 14400 kg/ha, or 14.4 tonnes, increasing in subsequent years. This compares with 2506 kg/ha in Run 1 with the hedgerows present. Contour-aligned hedgerows exert a strong protective effect on the soil.

In Output 5 - **Changes in soil carbon** (Table 14), the total carbon declines from the initial 17160 to 15877 kg/ha in Year 5. About 7.5% of the initial carbon has been lost in 5 years. Comparison of this output for runs 1 and 2 shows that the main reasons for the difference are first, the smaller gains from humification (the result of absence of the tree leaf litter) and the greater loss of carbon in eroded sediment.

Table 14. Model 4: Documentation and soil Carbon.

DOCUMENTATION

FILE NAME: MAIZE1
TITLE: MAIZE MONOCULTURE 1
SOURCE: USER'S HANDBOOK
COUNTRY: RURITANIA
LOCATION:
CYCLE: CARBON AND NITROGEN
NOTES: COMPARISON WITH HEDGINT1, ALL OTHER VALUES SAME
ASSUMPTIONS FOR OUTPUT:
DATE OF INPUT: 8.12.89
DATE OF OUTPUT: 8.12.89

5 CHANGES IN SOIL CARBON

TIME	TOTAL	GAINS HUMIFICN	ADDITIONS	LOSSES OXIDATN	EROSION
Init	17160				
1	16894.	439.	0.	515.	190.
2	16634.	436.	0.	507.	189.
3	16379.	432.	0.	499.	188.
4	16126.	427.	0.	491.	188.
5	15877.	422.	0.	484.	188.

Essentially, absence of the hedgerows has produced a gradually, but progressively, soil-degrading system, compared with the slightly soil-improving, almost stable, system under hedgerow intercropping. This is in agreement with the observed trend (although less in magnitude) in the reported trials on which this example is loosely based.

As expected, this soil degradation is reflected in the other outputs. Total plant-soil system carbon decreases (Output 6), as does soil organic nitrogen (Output 7). Output 8 shows that the supply of mineral nitrogen to the plants is only decreasing very slightly during the first 5 years. There is, however, a net loss of nitrogen from the plant-soil system (Output 9), and over a longer period this becomes reflected in the nitrogen supply to the crops (try a 20-year run of Output 8).

Since the decreases in nitrogen supply to plants and in soil depth are very small, the feedback effect of the soil upon plant growth is largely due to the decline in soil carbon. This causes slow but progressive decreases in plant growth (Output 11) and harvest (Output 12).

However, compare Output 12 - Harvest for Model 3 and Model 4 (Table 15). Although the rate of crop growth was the same for both, the harvest in Year 1 is higher for maize monoculture, 1600 kg/ha as compared with 1280 kg/ha under the hedgerow system. By obtaining 20-year outputs of Harvest for this model and for the corresponding hedgerow intercropping system (use the Utilities Menu to load HEDGINT1), it can be seen that the maize yield under monoculture only drops below that under hedgerow intercropping in Year 19 (a comparison of harvests over 40 years is given in Figure 8). This is a clear disincentive to the farmer to adopt hedgerow intercropping, even though maize monoculture may be soil-degrading. In this case, there is a gain in the harvest of 80 kg of pigeon pea; whether this is viewed as adequate compensation for the loss of maize is a matter of the farmer's requirements or economics.

This example should not be taken to indicate whether hedgerow intercropping is or is not preferable to maize monoculture. It may be preferable under some circumstances but not others. The intention here is to show how by using SCUAF you can use a set of data to estimate the consequences, short-term and long-term, of changing some element of a land-use system.

Examples for practice

If you have worked through the above examples, you should be able to:

- enter a new model;
- save a model;
- retrieve a model and modify selected items of data;
- obtain a set of outputs.

Details that have not been covered in the above introduction are explained in the account of inputs and outputs in Chapter 6.

Many users will now wish to enter and analyze data from their own experiments. For those who would like to explore the possibilities of SCUAF further, however, here are some possible exercises, with guidance as to the steps required.

Example 1. Take the same starting data as Model 1, but instead of shifting cultivation, substitute a planted tree fallow, harvested for fuelwood.

Table 15. Models 3 and 4: Harvest.

	Model 3 MAIZE MONOCULTURE	Model 4 HEDGEROW INTERCROPPING MAIZE/PIGEON PEA	
TIME	CROP FRUIT (maize)	TREE FRUIT (pigeon pea)	TREE WOOD
1	1600.	1280.	80.
2	1587.	1281.	80.
3	1574	1283.	80.
4	1556.	1285.	80.
5	1538.	1287.	80.
6	1520.	1289.	80.
7	1503.	1292.	80.
8	1485.	1294.	80.
9	1468.	1296.	80.
10	452.	1298.	81.
11	435.	1300.	81.
12	419.	1303.	81.
13	403.	1305.	81.
14	387.	1307.	81.
15	1372.	1309.	81.
16	1356.	1311.	81.
17	1341.	1313.	81.
18	1327.	1315.	81.
19	1312.	1317.	81.
20	1298.	1319.	81.
21	1284.	1321.	81.
22	1270.	1323.	81.
23	1256.	1325.	81.
24	1243.	1327.	81.
25	1230.	1329.	81.
26	1217.	1331.	82.
27	1205.	1333.	82.
28	1192.	1335.	82.
29	1180.	1337.	82.
30	1168.	1339.	82.

- Load Model 1, SHIFTCL1.
- Input 2 - **Documentation.** Change the file name and title.
- Input 7 - **Plant growth.** Replace the rates of tree growth (leaf, fruit, wood and root) with your own data for a fast-growing tree fallow. (Note that the calculation of roots as 40%, or any other proportion, of above-ground growth must be done manually and entered; it is performed automatically when first starting a new model, but not when modifying an existing model.)
- Input 9 - **Removals.** Specify the tree wood as harvested (fraction harvested = 1.0). Assume the tree leaf, however, becomes litter, so harvested fraction is 0. Then remove the loss in burning by answering 'No' to 'Are there any other losses...?'.

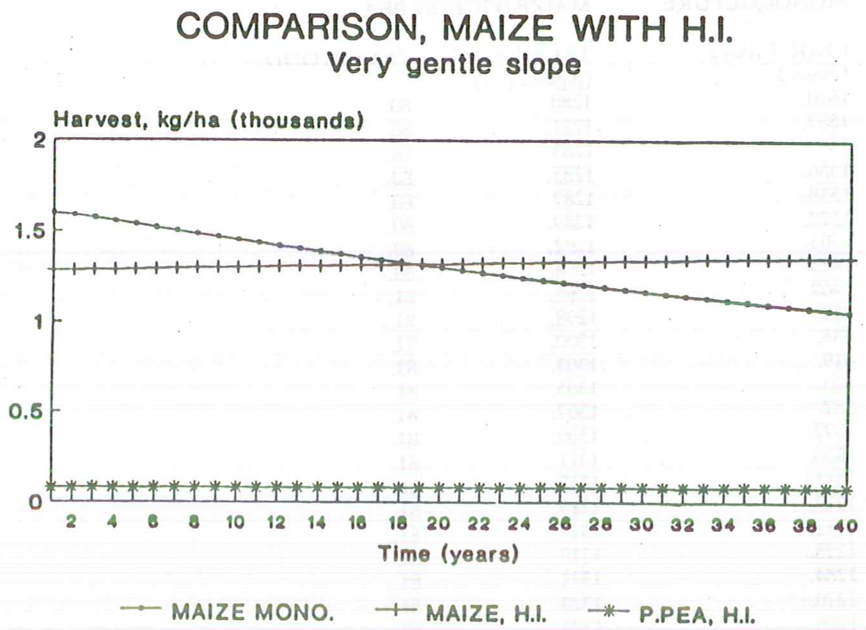

Figure 8. Models 3 and 4: maize vs hedgerow intercropping on very gently sloping land, comparison between harvests.

What effect does widening the hedgerow spacing have upon soil changes, and upon harvest?

Example 3. Take the same starting data as Model 3 but without any fertilizer.

- Load Model 3, HEDGINT1.
- Input 2 - **Documentation**, change the file name and title.
- Input 8 - **Additions.** Replace fertilizer added with 0.

Is the nitrogen-fixation from the hedgerows, at 20% area covered, sufficient to maintain the nitrogen economy of the system? Would a rotation with a leguminous crop (in addition to the hedgerows) help in this respect?

Example 4. Repeat the comparison between hedgerow intercropping and maize monoculture but on a less gentle slope than that used above.

- Load Model 3, HEDGINT1.
- Input 2 - **Documentation**, change the file name and title.
- Input 8 - **Additions**. Replace fertilizer added with 0.

Is the nitrogen-fixation from the hedgerows, at 20% area covered, sufficient to maintain the nitrogen economy of the system? Would a rotation with a leguminous crop (in addition to the hedgerows) help in this respect?

Example 4. Repeat the comparison between hedgerow intercropping and maize monoculture but on a less gentle slope than that used above.

Modify Models 3 and 4, in each case changing the Slope factor, under Input 6 - **Erosion**, to 1.0. If you wish to save these modified models, remember to alter the file names.

On more steeply sloping land, what are the relative effects on the soil of maize monoculture and hedgerow intercropping? What are the crop yields after 10 years? What is the relative sustainability of these two systems, and how does it compare with the same system on very gently sloping land? (Figure 9 shows the result of this comparison for harvest.)

Example 5. In the above examples, we have not covered a spatial mixed agroforestry system, such as coffee with shade trees. This you may wish to do, either using the default values as data or, better, substituting your own best estimates of data. These are the steps in outline.

- Enter the Utilities Menu and select 4 - **Clear current model**. Now move to the Input Menu.
- Input 2 - **Documentation**. Give the new model a file name and title.
- Input 3 - **Environment**. Enter the environmental conditions under which you would like to run the simulated model. This will set all the default values.
- Input 4 - **Agroforestry system**. The situation for this mixed agroforestry system is different from those encountered so far. Previously, the fractional areas under tree and crop components have added up to 1.0. In a coffee with shade trees system, however, some of the crop is growing underneath the trees. About 90% of the ground is planted to coffee bushes but the canopy of the shade trees covers, for example, 50% of the area. SCUAF can handle this situation. Enter area under tree as 0.5 and area under crop as 0.9.

Now enter data for Inputs 5-11, or accept the default values. Under Input 6 - **Erosion**, if you have chosen a steep slope, you may wish to reduce the very high calculated value of soil erosion. Under Input 7 - **Plant growth**, be careful to follow the rule for making plant growth estimates refer to hypothetical rates under 100% cover of tree and crop respectively (p.38).

You will have to make assumptions about whether the trees are pruned or allowed to grow. The outputs become more interesting if it is assumed that they are allowed to grow for, say, 15 years, and then felled all at once and harvested. To do this, enter Period 1 as 14 years and Period 2 as 1 year, a cutyear; and enter the harvest of tree wood in

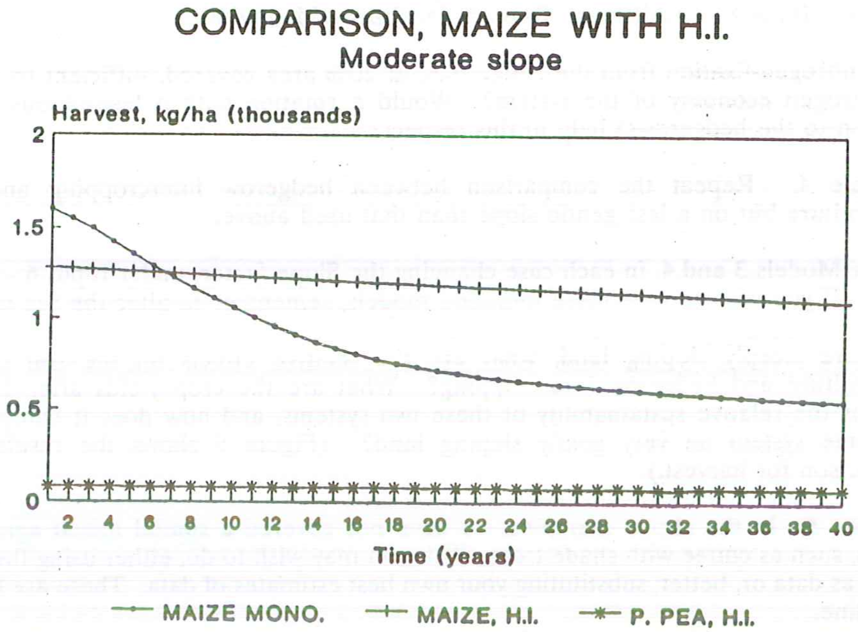

Figure 9. Maize vs hedgerow intercropping on moderately sloping land, comparison between harvests.

Input 9 - Removals, during the cutyear.

Does the system you have entered maintain soil fertility: (i) so long as there is no cutyear? (ii) despite removal of system carbon and nitrogen in the harvested wood in a cutyear?

For comparison, Figure 10 shows change in soil carbon for a mixed system of cacao with *Cordia alliodora*. There is a slow decline during the period of mixed cropping, but a rise in Year 20 when the *Cordia* are felled, giving a timber harvest, and the cacao cleared and replanted.

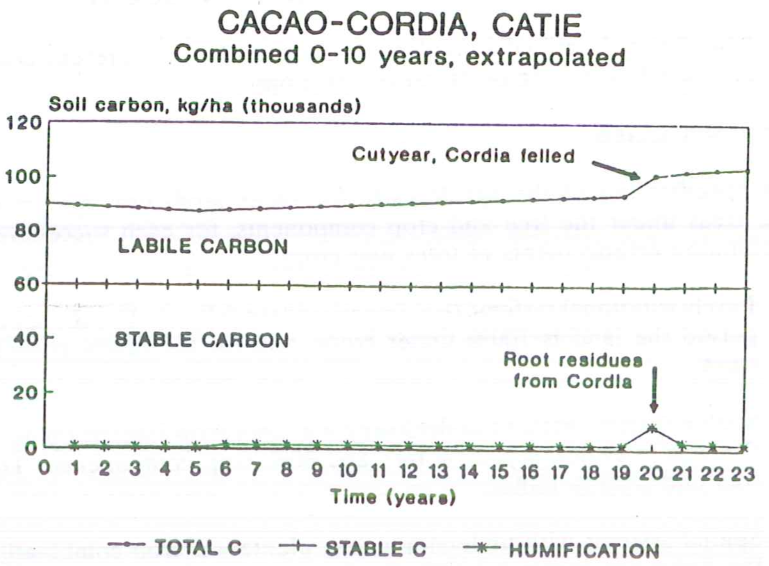

Figure 10. Mixed agroforestry system, cacao-*Cordia*: soil carbon.

PART II. A REFERENCE GUIDE

5 STRUCTURE AND FUNCTIONING OF SCUAF

The model has been described in outline in Chapter 2. This present chapter describes in more detail the functioning of its various sections.

The agroforestry system

The basic specification of the agroforestry (or other land- use) system is in terms of respective areas under the tree and crop components, for each successive year. There are four common arrangements of trees and crops:

1. Purely rotational systems (e.g. improved tree fallow). For the specified cropping period the land is 100% under crops, and for the fallow period 100% under trees.

2. Spatial systems without understorey, e.g. hedgerow intercropping. For all years, the land is under, say, 20% tree and 80% crop components. The total under tree and crop is 100%.

3. Spatial systems with understorey, e.g. plantation crop combinations. Some of the crops are grown beneath the tree canopy; the respective areas therefore add up to more than 100%, e.g. 40% trees and 90% crops.

4. Systems with both spatial and rotational components, e.g. taungya, rotational hedgerow intercropping.

The areas under trees and crops are in fact specified as fractions, e.g. 40% as 0.4. The way in which systems are specified, as a series of periods, is explained on p.75.

In some agroforestry systems, the trees are allowed to grow for a number of years and then felled, coppiced or otherwise cut. Such a year is known as a **cutyear**. Besides the management operation of cutting, there is usually an additional harvest of wood during a cutyear.

The user also specifies what proportions of the tree and crop components consist of nitrogen-fixing plants.

The areas under trees and crops are specified under the model input, 'agroforestry system'. Other elements of the system, in the wider sense of the term, are entered as 'additions' and 'removals'.

Additions are any material brought into the plant-soil system. These may be organic or inorganic. Organic additions are mulch, compost and farmyard manure, if the material in these originates from outside the system, e.g. grass mulch from outside, or tree litter cut from natural forest (for treatment of manure, see pp.67, 81). The carbon and nitrogen contents of organic additions are specified. Inorganic additions refer to fertilizer, in Version 2 of SCUAF to its nitrogen content only.

Removals may be harvest or other losses. Harvest includes not only fruit (crop and tree) but any removal for productive purposes, e.g. tree leaf for fodder, woody parts of tree prunings if used for fuelwood. There may be an additional harvest in cutyears, usually of tree wood as timber or fuelwood. In some systems there are losses of plant material that are not for the benefit of users of the system, principally burning. For modelling purposes, harvest and other losses are treated the same, the difference being that other losses do not appear in the printed output of harvest.

The plant compartment

The plant compartment is the same for the carbon and nitrogen cycles (Figure 11). The two plant components, tree and crop, each have four parts: leaf, fruit, wood and root. The net primary production of these eight plant parts is specified in terms of net primary production (NPP) of dry matter (DM), as kg DM/ha/yr. This is converted to plant carbon, by default at 50% of dry matter, and to nitrogen, by specifying the carbon: nitrogen ratios of each plant part. If nitrogen content is available as percentages, from plant tissue analysis, these are converted to ratios for input.

Plant NPP is entered into the model as that which would take place if the whole land area were covered by that plant. These data are then multiplied by the proportional areas under each plant, to give the production for the system. For example, if the tree NPP is 20 000 kg DM/ha/yr and the tree component occupies 0.2 of the area of the agroforestry system, then the tree NPP of the system is 20 000 x 0.2 = 4000 kg DM/ha/yr.

Each plant part may follow one of four paths:

1. Growth. Those proportions of plant parts, usually wood and root, which remain as standing biomass at the end of the year. SCUAF monitors the growing biomass of perennial plants.

2. Harvest. This includes not only fruit (crop and tree) but any removal for productive purposes, e.g. tree leaf for fodder, woody parts of tree prunings if used for fuelwood.

3. Other losses. These are removals from the system for non-productive purposes, e.g. burning.

4. Litter. This term covers all plant material, above-ground and roots, that becomes available for decomposition by soil fauna.

Growth, harvest and other losses are specified by the user. Litter is the residual amount of each plant part after these have been subtracted.

The 'growth' plant material is transferred to the next year of the cycle, as standing biomass. This continues from year to year until the user specifies a cutyear. A cutyear is a year in which perennial plants are felled, coppiced or otherwise 'cut' in a way different from previous years; the above-ground cut material may be harvested, e.g. as timber, or otherwise removed (e.g. burnt). In rotational agroforestry systems a cutyear occurs at the end of a period under the tree component; in spatial systems, it occurs if the trees are allowed to grow for some years and then cut. What is not harvested or removed becomes cutyear litter, which is added to the annual litter for that year.

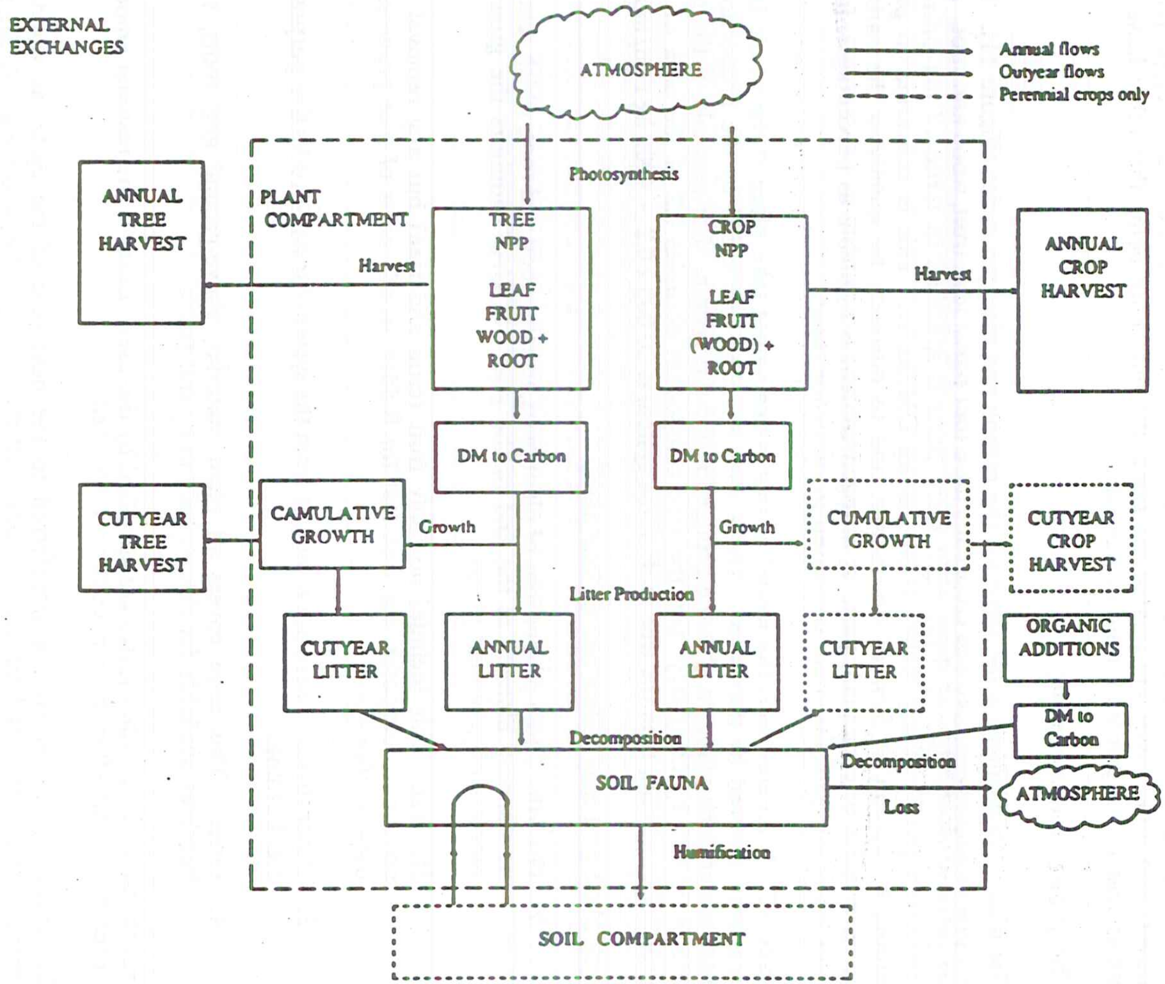

Figure 11. The SCUAF plant compartment.

If there are organic additions from outside the system, e.g. mulch, compost or farmyard manure, these are treated as if they were a further source of litter, with specification of their carbon and nitrogen contents.

The outputs from the plant compartment of the cycle are:

1. Harvest: annual and cutyear. This is both an output in the sense of being a removal from the plant-soil system, and also a printed output from the program (Output 12).

2. Litter: the mass of carbon and nitrogen entering the decomposition subsystem. There are potentially 17 elements of litter: leaf, fruit, wood and root, from tree and crop, annually and in cutyears, plus organic additions.

The soil compartment

The organic material leaving the plant compartment, or litter, becomes an input to the soil compartment of SCUAF. There are three elements to the soil compartment: erosion, the carbon cycle and the nitrogen cycle. Erosion is calculated first as total soil loss and then as losses of carbon and nitrogen. These latter are transferred as data for the carbon and nitrogen cycles respectively. The soil carbon balance is calculated next. The nitrogen cycle is linked to that of carbon in two ways: first, organic matter decomposes as a whole, releasing carbon and nitrogen in proportion to their respective contents and second, soil organic matter will only accept nitrogen at its own carbon:nitrogen ratio.

Erosion

Soil erosion is calculated from a simplified version of the universal soil loss equation (USLE) (Wischmeier and Smith, 1978; FAO, 1979):

$$\text{Erosion (kg/ha/yr)} = R \times K \times S \times C \times 1000$$

where R = climate factor, K = soil erodibility factor, S = slope factor (LS in the USLE) and C = cover factor. 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). The factor of 1000 is to convert from the unit of tonnes employed in the USLE to that of kilogrammes used in SCUAF.

When these factors have been entered, the model calculates values of erosion separately for the tree and crop components, and displays them. For rotational agroforestry systems, these values are used in the respective years under the tree or crop components. For spatial systems, the user enters the tree proportionality factor (see below). The model then displays the calculated rate of erosion for the system as a whole. The calculated values both for the tree and crop components alone and for a combined spatial system can be over-ridden if the user enters measured rates of erosion.

Having obtained erosion as kilogrammes of soil per hectare per year, losses of carbon and nutrients are calculated together with reduction in soil profile depth. For carbon and nutrients, the proportions present in the original topsoil are multiplied by enrichment factors for eroded sediment. For example, erosion of 5000 kg/ha/yr from a topsoil with

0.1% nitrogen and a nitrogen-enrichment factor of 0.4 would produce a loss of 5000 x 0.001 x 4.0 = 20 kg N/ha/yr. Change of profile depth is calculated from dry bulk density.

This gives erosion of soil, carbon and nutrients for the initial year. For subsequent years, climate and slope will remain the same but the soil and cover factors will be modified, with increase or decrease in soil organic matter and in plant growth. These are calculated in year-by-year iterative fashion.

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 (Figure 12). Consider, as an example, erosion rates of 1000 kg/ha/yr under trees and 30 000 kg/ha/yr under crops, and consider an agroforestry system consisting of 50% trees and 50% crops. At one extreme, it could be assumed that erosion within the agroforestry system was proportional to the rates of soil loss under the tree and crop components multiplied by the proportions which each occupies, in this example (1000 x 0.5) + (30 000 x 0.5) = 15 500 kg/ha/yr. At the opposite extreme, the tree component might completely control the erodibility of the system as a whole, reducing erosion to the same rates as it would be under a pure tree cover, 1000 kg/ha/yr.

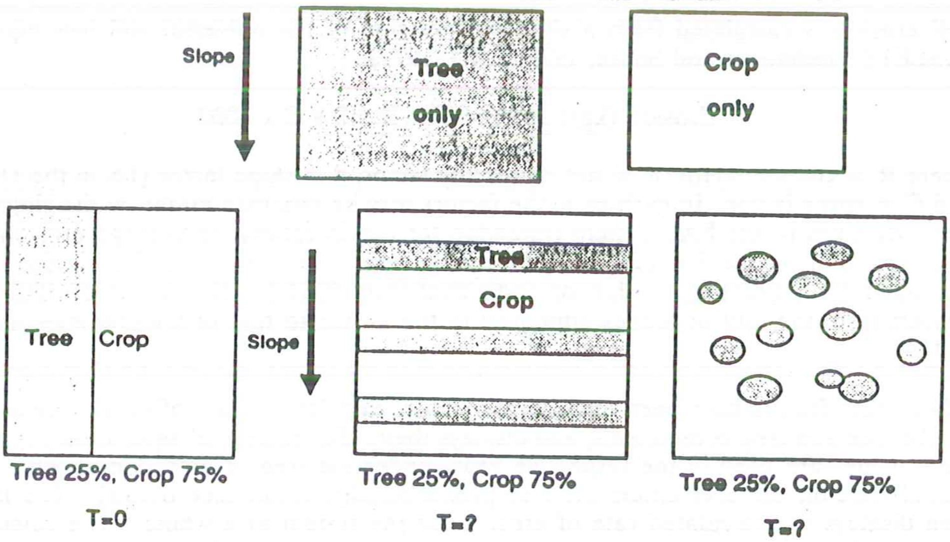

Figure 12. The tree proportionality factor.

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 (Young and Muraya, 1988). 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, then 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 1-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 hedgerow intercropping 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.

The carbon cycle (Figure 13)

The carbon cycle as modelled in SCUAF rests on a review of research into soil organic matter formation and decomposition. This is set out in Chapter 9 of Young (1989), which should be referred to for evidence and references. Only the basic features, leading to the concepts and processes used in SCUAF, will be outlined here.

Plant residues (litter) are transformed into the soil organic matter (humus) by soil meso- and micro-organisms. The first stage is comminution or physical breaking up into small particles, whilst later stages involve complex biochemical transformations. During this transformation, the carbon from the litter temporarily enters the soil faunal biomass, a fraction known as 'active carbon' in some models; in seasonal climates, its mass varies through the year, SCUAF operates in whole-year units only, and makes a major simplification by treating the size of biomass carbon as effectively constant. That is, whilst recognizing that biomass exists as a store, it is assumed that the amounts entering and leaving it annually are the same, and thus it is effectively treated as a process.

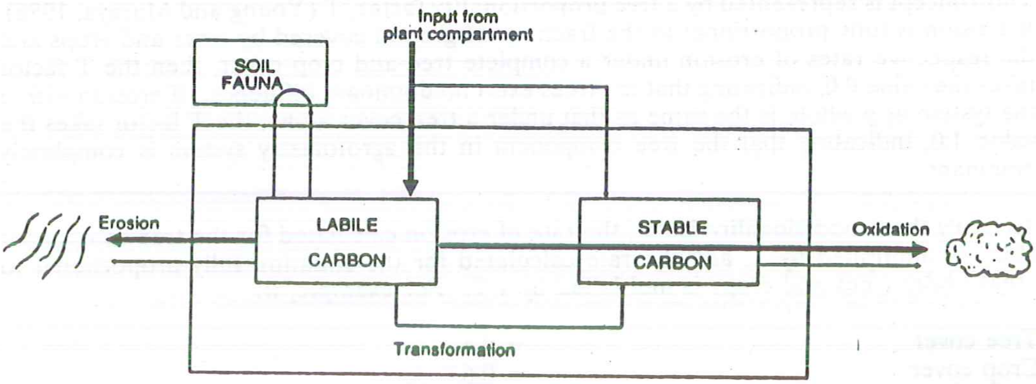

Figure 13. The SCUAF carbon cycle.

During the process of transformation of litter to humus, a substantial proportion of carbon is used by microorganisms for energy and lost as carbon dioxide. This loss amounts to more than half of the litter carbon, varying with type of plant tissue and other factors (Swift et al., 1979). Oxidation loss during transformation from litter to humus is referred to as litter-to-humus conversion loss. It is specified as a fraction, the default values being higher for above-ground plant parts than from roots and organic additions, and (following the model of Parton et al., 1987) higher for sandy soils.

By means of isotopic labelling of plant material, using carbon-14, this conversion loss can be followed. Labelled carbon added to soil disappears as a two-part curve: a rapid fall, which in the tropics takes 3-6 months, followed by a slower, negative exponential, decay. The initial rapid decay is assumed to correspond to the conversion loss.

Once converted to soil humus carbon, further oxidation loss takes place, but at a much slower rate, dependent on the mass of carbon initially present as a substrate for micro organisms. This is represented by:

$$C_{t+1} = C_t \times (1 - k)$$

where C_t is the carbon in year t, C_{t+1} the carbon one year later, and k the decomposition constant. This relation expresses the fact that the rate of soil biological activity, and thus oxidation loss, depends on the amount of soil carbon initially present that acts as a substrate for micro-organisms. For the lowland tropics, typical values of k are 0.03-0.04, that is, a loss of 3-4% of the soil carbon each year.

It is generally assumed that the decomposition constant is higher on cultivated land than under forest. SCUAF adapts this by allowing the constant to be specified separately for the tree and crop components of the agroforestry system. The decomposition constant for the system as a whole is calculated *pro rata* for the areas under each component.

In isotope studies, the same relation is commonly expressed as:

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

where e is the exponential constant and r a constant. For values less than 0.1, r is nearly the same as the decomposition constant k. SCUAF adopts the former equation, using k.

Humus fractions

A further finding from isotope-labelling studies is that there are two fractions of soil humus carbon, which are called in SCUAF labile and stable carbon. **Labile carbon** is that referred to above, decomposing according to the decomposition constant. **Stable carbon** decomposes much more slowly, although there are no reliable estimates for the rate. The most widely held view is that stable carbon originates by microbial transformation of labile carbon, although a minority view is that some of it derives directly from lignin-rich plant litter.

Apart from the fact that it forms part of the carbon identified in standard soil analysis and decomposes slowly, very little is known about stable carbon. The presence in a model of a component the behaviour whose is unknown presents a dilemma for modelling! The effect of assuming the presence of stable humus is considerable; it acts as a buffer, slowing down carbon loss.

A way out of this problem lies in the fact that stable humus is (probably) very little affected by management. Its amount changes little over periods of the order of 10-20 years. Furthermore, as it decays very slowly, it releases few nutrients. Its contribution to soil physical properties is not known.

It is, therefore, largely the labile 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 management. It is also known from experience that the greatest changes in soil carbon take place within the topsoil. Furthermore if, as seems likely, all or most plant litter first becomes labile humus, then most carbon in the topsoil will be of this type. This leads to the following approximation, known as the **one-fraction assumption**:

- most topsoil carbon is in labile form, whilst much of the carbon in lower horizons is in stable form;
- management largely affects topsoil carbon;
- therefore in runs of SCUAF, it is recommended to model carbon changes in the topsoil only and, as an approximation, assume that all topsoil carbon is labile.

The user is free to make the alternative **two-fraction assumption**, namely that part of the soil humus exists in stable form. This may be more realistic if the whole soil profile, instead of the topsoil only, is used for modelling.

If the two-fraction assumption is made, the user is asked to specify:

- the proportion of initial soil carbon that is in stable form;
- the decomposition constant for stable humus;
- what proportion, if any, of litter is converted directly to stable humus;
- what proportion of labile humus is transformed annually to stable humus.

If the model is run on the two-fraction assumption with the default values, the amount of stable humus will remain constant, only labile humus and will vary. The default values are chosen so as to make stable humus stable!

The soil carbon balance (Figure 13)

In the **one-fraction assumption**, the balance of soil humus carbon is calculated as:

Soil carbon at end of year	=	Soil carbon at end of previous year
	+	Gains from humification of litter
	-	Loss in eroded soil
	-	Loss from humus oxidation

In the **two-fraction assumption**, all the carbon lost in eroded soil is assumed to be labile, on the grounds that it is derived from the topsoil. The balance is then as follows:

	Labile carbon	Stable carbon
Gains:	Humification of litter to labile carbon	(Humification directly to stable carbon, if any)
		Transformation from labile to stable carbon
Losses:	Erosion	
	Oxidation, at rate for labile carbon	Oxidation, at (slower) rate for stable carbon
	Transformation from labile to stable carbon	

The nitrogen cycle (Figure 14)

The plant compartment is the same for the nitrogen cycle as for the carbon cycle. Plant residues which are not harvested or otherwise removed reach the stage of litter with their contained nitrogen. Plants translocate nitrogen between their parts at different stages of growth, e.g. out of senescent leaves into fruit. The nitrogen contents specified for plant parts should be those at the time at which they leave the plant compartment. Thus, plant leaf is likely to have a higher nitrogen content if added to the soil as prunings than as natural litter fall, because nitrogen is translocated out of leaves before they are shed.

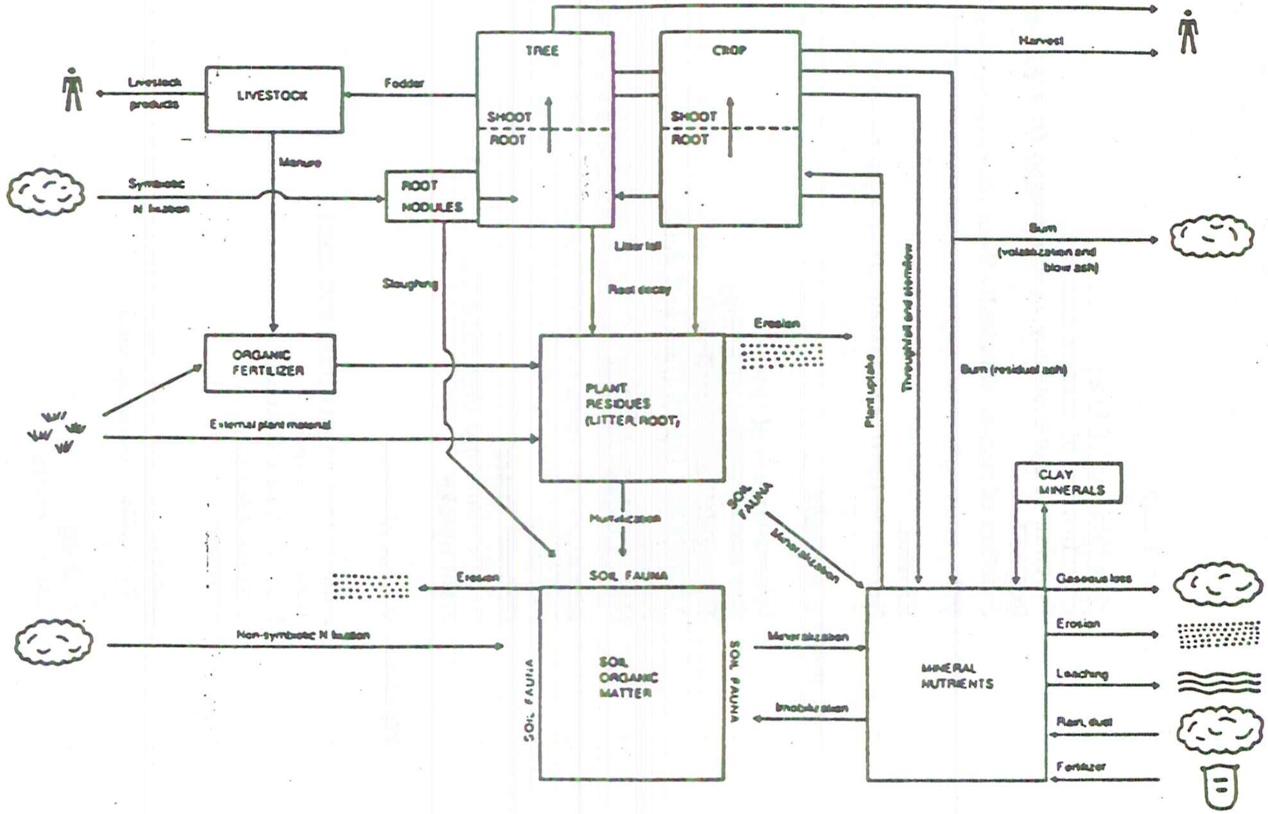

Figure 14. The SCUAF nitrogen cycle (Young, 1989).

The nitrogen cycle within the soil compartment can be considered as three balances: soil organic nitrogen, soil mineral nitrogen and plant-soil system nitrogen. The respective gains and losses are (Figure 15):

Soil organic nitrogen

Gains:
- Humification of litter
- Humification of organic additions
- Fraction of symbiotically fixed nitrogen (if any) passing into soil
- Fraction of non-symbiotically fixed nitrogen passing into soil

Losses:
- Erosion
- Net mineralization (mineralization minus immobilization)

Soil mineral nitrogen

Gains:
- Mineralization of litter
- Net mineralization of humus
- Throughfall and stemflow
- Atmospheric inputs (rain and dust)
- Fertilizer
- Non-symbiotic fixation

Losses:
- Erosion
- Leaching
- Gaseous losses
- Net fixation onto clay minerals
- Plant uptake

Plant-soil system nitrogen

Gains:
- Atmospheric inputs (rain and dust)
- Symbiotic fixation
- Non-symbiotic fixation
- Organic additions
- Fertilizer

Losses:
- Harvest
- Other losses (burning, etc.)
- Erosion
- Leaching
- Gaseous losses

The transfer of nitrogen from litter to humus is governed by the principle that soil will only accept new carbon and nitrogen at its existing carbon:nitrogen ratio. Thus if the soil carbon:nitrogen ratio is 10 and the amount of humified carbon is 4000 kg C/ha/yr, then the amount of humified nitrogen is 4000/10 = 400 kg N/ha/yr. Litter nitrogen that is not accepted by the soil is assumed to become mineral nitrogen.

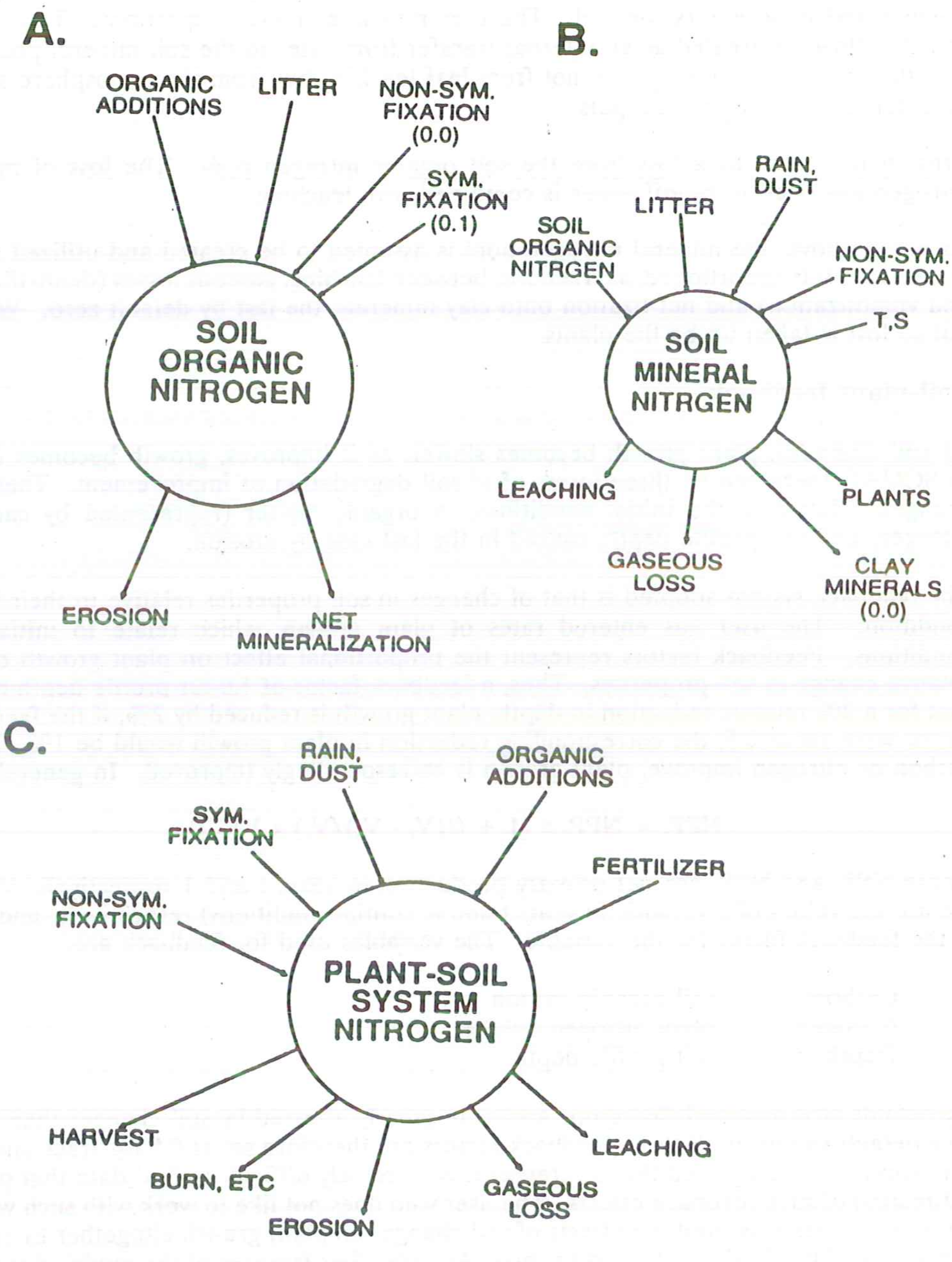

Figure 15. Subsystems of the nitrogen cycle.

By default, 90% of symbiotically fixed nitrogen enters the plants directly and 10% is sloughed off into the soil, whilst all non-symbiotic fixation enters the mineral nitrogen fraction and none enters the soil. The user may alter these proportions. Throughfall and stemflow are treated as an internal transfer from litter to the soil mineral pool; any part that is believed to originate not from leaf leaching but from the atmosphere should be entered as atmospheric inputs.

Erosion is treated as a loss from the soil organic nitrogen pool. The loss of mineral nitrogen dissolved in runoff water is combined with leaching.

As noted above, the mineral nitrogen pool is assumed to be created and utilized afresh every year. It is apportioned, as fractions, between leaching, gaseous losses (denitrification and volatilization) and net fixation onto clay minerals, the last by default zero. What is not so lost is taken up by the plants.

Soil-plant feedback

As soil degrades, plant growth becomes slower; as it improves, growth becomes faster. In SCUAF, there can be three forms of of soil degradation or improvement. These are changes, relative to the initial conditions, in organic matter (represented by carbon), nitrogen, and soil profile depth, caused in the last case by erosion.

The feedback system adopted is that of changes in soil properties relative to their initial condition. The user has entered rates of plant growth, which relate to initial soil conditions. Feedback factors represent the proportional effect on plant growth of any relative change in soil properties. Thus, a feedback factor of 1.0 for profile depth means that for a 2% relative reduction in depth, plant growth is reduced by 2%; if the feedback factor were set at 0.5, the corresponding reduction in plant growth would be 1%. If soil carbon or nitrogen improve, plant growth is correspondingly improved. In general:

$$NPP_t = NPP_1 \times (1 + (((V_t - V_o)/V_o) \times VFF))$$

where NPP_t and NPP_1 are net primary production in years t and 1 respectively, Vt and Vo are the values of a variable in years t and 0 (initial conditions) respectively, and VFF is the feedback factor for the variable. The variables used for feedback are:

Carbon:	soil organic carbon
Nitrogen:	plant nitrogen uptake
Depth:	soil profile depth

By default, it is assumed that crops are more greatly affected by soil changes than trees. The default values of all three feedback factors are therefore set at 0.5 for trees and 0.25 for crops. It is recognized that at present it is extremely difficult to find data that permit estimation of such feedback effects. The user who does not like to work with such weakly based estimates may omit the effects of soil changes on plant growth altogether by setting the values of the feedback factors to zero. As with other features of the model, this is not taken as a reason to omit such effects altogether; rather, it is hoped that it will stimulate research.

Treatment of livestock in SCUAF

The present version of SCUAF is designed primarily for agrosylvicultural systems. User who wish to apply it to sylvopastoral systems may do so, but many of the default values, both of variables and for processes, may require modification.

However, many agrosylvicultural systems incorporate an animal or livestock element, the presence of which can affect soil properties to a greater or lesser extent. Specifically, tree leaf material and crop residues are often fed to livestock, and farmyard manure added to the soil. This may be done through browsing on the site, stall-feeding or an element of both.

It would be possible to offer the option of a livestock store, of carbon and nitrogen, within the land-use system, together with a conversion factor to represent relative losses in passing through the bodies of animals, and for harvest of livestock products. However, livestock are likely to acquire part of their food from outside the land-use system under consideration, whilst some or all of the manure may be applied to a different land-use system, such as a vegetable garden. In these circumstances, any form of 'conversion' would be difficulty to apply.

For these reasons, livestock can be included in SCUAF, but as an element external to the system (Figure 16). Plant material (tree, crop) harvested from the system and fed to livestock is recorded as harvest (and thus as a benefit from the system, independently of the livestock products). Farmyard manure brought into the system is treated as an organic addition.

The arrangement in Figure 16 is a reasonable representation of what happens in a stall-feeding system, although somewhat artificial where livestock directly browse the land.

Thus it is possible, in the SCUAF model, to feed plant residues to livestock and return the farmyard manure to the soil--but the transfer must be made by hand!

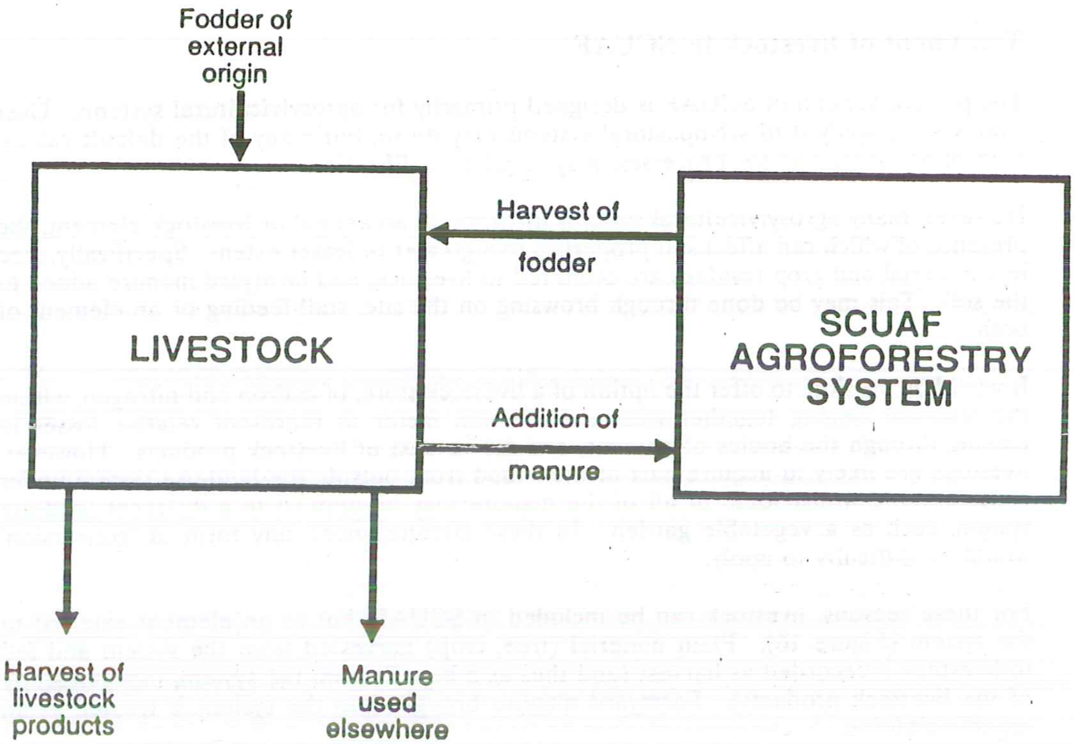

Figure 16. Treatment of the livestock component in SCUAF.

6. USER'S GUIDE TO SCUAF

This Chapter is a guide to the use of SCUAF, giving instructions for inputs, outputs and other facilities. It should be read in conjunction with the description of the nature and functioning of the model, given in Chapter 2.

General operating instructions

All operations, for both inputs and outputs, are followed by pressing the RETURN (or ENTER) key. This will no longer be stated.

> **PITFALLS**
>
> As in all computer programs there are some pitfalls, where the user unfamiliar with the model can easily go wrong. These are shown in this way.

Getting started

> YOU MUST SET SUBDIRECTORIES ACCORDING TO THE INSTRUCTIONS GIVEN IN 'GETTING STARTED' ON PAGES 13-15, OTHERWISE THE PROGRAM WILL CRASH.

The operations which set up the necessary subdirectories, load SCUAF, and start a run of a model, are described in "Getting started" on p.00. Follow these until you have brought the Main Menu onto the screen (Table 16).

The Main Menu offers a choice between three subsidiary menus or to exit from the model. Select 1, 2, 3 or 99 as required:

1 - Input Menu. This is to enter data for a new model, or edit data for an existing model. Details commence on p.70.

2 - Output Menu. This is to produce the various outputs from a model. Details commence on p.85.

3 - Utilities Menu. This is to save data in a model that has been entered, or to load a model that has been previously saved. Details commence on p.95.

99 - Exit. When you have finished a session, or want a break, return to the Main Menu and press 99. A prompt will ask whether you wish to save the current model, that is, store the model you have been working on with all the most recent alterations. To save the model, answer Y. If it has already been saved (see Utilities Menu), or is not required, answer N or simply press the RETURN key to enter the default value, N.

Table 16. The SCUAF Main Menu.

```
SCUAF VERSION 2.0

MAIN MENU

1  -  Input Menu
2  -  Output Menu
3  -  Utilities Menu

99 -  Exit from SCUAF

SELECT THE FUNCTION YOU REQUIRE
```

To start a new model:

- Select the Input Menu; enter data.
- If the data are to be kept for future reference, select the Utilities Menu and save the model. If you are just doing test runs, there is no need to do this: outputs can be obtained without saving.
- Select the Output Menu; obtain outputs.
- Return to the Main Menu and exit.

To edit (modify) a previously-saved model:

- Select the Utilities Menu; load the model.
- Select the Input Menu; edit the data.
- Select the Utilities Menu; save the edited model.
- Select the Output Menu; obtain outputs.
- Return to the Main Menu and exit.

You may move between the Input and Output Menus as often as you wish, changing one or more values of inputs to see what effect these changes have upon outputs. If doing this, take care to label each output, using Input Menu 1 - Documentation.

To display outputs from a previously-obtained model:

- Select the Utilities Menu; load the model.
- Select the Output Menu; obtain outputs.
- Return to the Main Menu and exit.

The Input Menu (Table 17)

The Input Menu consists of 11 groups of data. To start a new model, proceed through these in sequence. To edit an existing model, select any menu items, in any order.

All input data are entered in response to screen prompts, or questions. **Default values** (p.10) appear in square brackets [ ] after prompts. **By pressing the RETURN key, without entering data, you retain the default values.**

Table 17. The SCUAF Input Menu.

```
INPUT MENU

1  -  Select Cycle
2  -  Input/Modify Documentation
3  -  Input/Modify Environment
4  -  Input/Modify Agroforestry System
5  -  Input/Modify Soil
6  -  Input/Modify Erosion
7  -  Input/Modify Plant Growth
8  -  Input/Modify Additions
9  -  Input/Modify Removals
10 -  Input/Modify Soil Processes
11 -  Input/Modify Soil/Plant Feedback Factors

99 -  Exit from input menu

SELECT FUNCTION (0 = MENU)
```

In starting a new model, it is essential as a minimum to work through Inputs 5 - Soil, 6 - Erosion and 7 - Plant Growth, as these contain variables which are preset to an artificial value of -1 (see p. 00).

Input data are entered in four forms: text, numerical, coded and Yes/No, for example:

Text values, e.g.:

Country: [ ]
Date of input: [ ]

Any text, letters or numbers, will be accepted. The default values in the above examples are blanks.

Numerical values, e.g.:

Fraction of land under tree [0.400]
Initial soil carbon (kg/ha) [26000]

Most values of **quantities** are given as kg ha^{-1} or kg ha^{-1} yr^{-1}, expressed on the screen and in printed outputs as kg/ha and kg/ha/yr. The units are kilogrammes of plant dry matter (DM), carbon (C) or nitrogen (N). Most values for **proportions** are given as fractions, not percentages; for example, if 40% of the land is under the tree component, this is entered as the fraction 0.4. There are a few exceptions, in cases where data available to the user are normally given in other forms (e.g. initial soil carbon as a percentage) or where other units are required (e.g. soil depth as centimetres).

A value of 3.0 can be entered as 3.0 or 3. or 3
A value of 0.3 can be entered as 0.3 or .3

If you reply to a numerical question with characters other than numbers, the program will retain the existing value and pass on to the next question.

Coded values, e.g.:

Select one of the following soil textures:
1 Medium textured
2 Sandy
3 Clayey

Current soil texture = Medium textured

Answer 2, and the soil texture used in the model will become Sandy, although the displayed texture does not change until this input is used again. Answers other than the numbers specified produce a repeat of the question.

Yes/No answers, e.g.:

Any more periods? Y/N [N]

Answer Y for yes and N for no.

The following is a guide to the entry of each group of input data, with the consequences of certain replies. It should be read in conjunction with the prompts (questions) which appear on the screen.

If you obtain results which look unlikely, carefully check the data for such errors.

The **SCUAF data input form** is given as Appendix 1.

In programming *SCUAF*, *limits to the values of variables have* not been set--as it is commonly said, the program has not been 'idiot-proofed'. It is therefore possible to obtain totally incorrect results if you have made some major slip entering data, for example entering 20000 as 2000, or 40 (as a percent) when the program asks for 0.4 (as a fraction).

If you obtain results which look unlikely, carefully check the data for such errors.

1 SELECT CYCLE

If 1 - Carbon Cycle, is selected, modelling will cover soil erosion, the cycling of organic matter (represented by carbon) and the effects of changes in soil organic matter and soil depth upon plant growth. If 2 - Carbon and Nitrogen Cycles is selected, modelling will cover all of the preceding and additionally, nitrogen cycling and the effects of changes in available nitrogen on plant growth.

2 DOCUMENTATION

This group of inputs is intended for use it as a title, printed before any set of outputs. It is recommended (but not essential) that the computer keyboard be set to capitals.

As the **File Name**, enter any name of up to eight letters, or letters and numbers beginning with a letter. It is convenient to identify successive runs of the same basic model e.g. TESTNAME. with the same 7 letters followed by a different data items changed by a number, e.g. TESTRUN1; TESTRUN2.

If the model is saved, it will be stored as FILENAME.SCU. All outputs will be stored on disk as FILENAME with an extension indicating the type of output (p.107).

As the **Title**, enter any title of up to 40 characters by which you will recognize the model, or successive run, e.g. MINDANAO SHIFTING CULT.; BUNDA HEDGE INTERCROP. RUN 1. The Title appears in the prompts for graphical plotting of outputs.

The remaining items of documentation are non-functional, other than as a means of identification of the model and run. **Source** could be, e.g., ORIGINAL DATA; SMITH (1989); SIMULATED DATA. **Country** and **Location** are self-explanatory. Under **Cycle**, the cycle selected will appear, and can only be changed within Input 1.

Under **Notes** and **Assumptions for output**, anything can be entered, with a maximum of 60 characters for each. The intention is that **Notes** should be used for comments on the model as a whole, e.g. NO DATA ON ROOTS; and **Assumptions for output** for recording differences between successive runs, e.g. AS TESTRUN1 BUT WITH CROP RESIDUES REMOVED.

3 PHYSICAL ENVIRONMENT

This group of inputs has only one function: to set the default values. After the complete set of inputs has been entered, either accepting defaults or, where possible, substituting observed values, these environmental inputs play no further part in the functioning of the model. Since their function is simply to set reasonable values for missing data, the classes of climate, soil and landform properties are broad and their definitions generalized; the latter are based on the ICRAF environmental data base (Young, 1985).

CLIMATIC CLASS

The default is arbitrarily set as Lowland subhumid, and the user should always enter the climatic class.

Climatic Class		Meaning or definition
1	Lowland humid	Rain forest ecozone; Köppen classes Af and Am; approximate rainfall >1500 mm with <4 dry months.
2	Lowland subhumid	Savanna ecozone; Köppen classes Aw and Aw"; approximate rainfall 600-1500 mm with 4-8 dry months.
3	Lowland semiarid	Semi-arid or sahel ecozone; Köppen Class BS (in part); approximate rainfall 250-600 mm with 8-10 dry months.
4	Highland humid	Köppen Cf, Cm
5	Highland subhumid	Köppen Cw, Cw"
6	Highland semiarid	Köppen BS (in part)

The boundary between Köppen A and C climates is defined as a mean temperature of the coldest month of 18°C. A very approximate guide is that highland or C climates occur above 1200 m altitude near the Equator, falling to sea level near latitudes 30° North and South.

SOIL TEXTURE

1	Medium textured (default)	Soils other than as defined below including soils which are technically clays but are finely structured and permeable
2	Sandy	Soils dominated by sandy textures (sand, loamy sand, sandy loam)
3	Clayey	Soils dominated by heavy clay

SOIL DRAINAGE

1	Free (default)	Including excessively drained, moderately well drained
2	Imperfect	Imperfectly drained, seasonal waterlogging
3	Poor	Including poorly, very poorly drained; waterlogged for much of the year

SOIL REACTION

1	Strongly acid	pH <5.0
2	Acid (default)	pH 5.1-6.4
3	Neutral	pH 6.5-7.5
4	Alkaline	pH >7.5

SLOPE CLASS

1	Flat	Slope close to 0°, 0%
2	Gentle (default)	Slope <5°, <8%
3	Moderate	Slope 5°-17°, 8-30%
4	Steep	Slope >17°, 30%

The selection of 1 - Flat has the effect of setting the default value for erosion to 0.

It is not advisable to change the values of factors of the physical environment during the running of a model, as this may result in hidden changes to other variables. If you wish to test the same conditions but in a different environment, clear the current model and recommence.

4 AGROFORESTRY SYSTEM

The specification of the agroforestry system is critical to the operation of SCUAF. It is a fundamental assumption that the soil responds differently to the tree and crop components, and to which parts of them are harvested. One of the basic applications of the model is to examine the effects of varying the proportions of tree and crop components, or of harvesting plant residues (tree and crop) as compared with returning them to the soil.

The agroforestry system is described as a sequence of **periods**, each a specified number of years long. Within each period, there may be different proportional areas under the tree and crop components. A period one year long may be specified as a **cutyear**, a year in which the tree component is felled, coppiced, etc. and/or harvested differently from other years (p.54).

The default values for **Length of period, Fraction of land under tree and Fraction of land under crop** are arbitrary.

Note the use of fractions, not percentages. If crops are grown beneath the tree canopy, the fractions need not add up to 1.0. If the period is 1 year, the user is asked if it is a cutyear.

For systems with multiple cropping, either as intercrops or two crops per year, 'crop' refers to the combined crops (p.103). SCUAF operates in whole-year periods only.

If nitrogen cycling is being considered, questions appear on what fractions of the tree and crop are nitrogen-fixing. Stating the proportion of trees in the system that are nitrogen-fixing is straightforward. For multiple cropping, 'crop' refers to all crops grown; thus, for example, maize and beans grown either as equal-area intercrops or as a rotation of two crops per year would both be specified as 0.5 nitrogen-fixing.

After all periods specified have expired, Period 1 returns. Thus for a purely spatial system, all that is necessary is to specify one period, of any length.

A wide variety of agroforestry systems, rotational and spatial, can be described by these means, together with the specification of additions and removals in Inputs 8 and 9. Examples are given in Table 24 and Chapter 7.

5 INITIAL SOIL CONDITIONS

Initial soil conditions gives the relevant soil conditions as they are at present, observed or assumed, as a basis for predicting changes in the future. It is fundamental to SCUAF that the rates of plant growth, as entered below, are what they are observed (or expected) to be on this initial soil.

Three soil depths are asked for: topsoil, soil depth considered, and total soil depth. **Topsoil** is the relatively humus-rich surface horizon, or in cultivated soils the plough or hoe layer. **Total soil depth** is the effective depth for plant growth: this is for estimation of the effect of erosion upon growth, loss of depth being relatively more serious for shallow soils.

Soil depth considered is a basic choice in running the SCUAF model: whether to consider the topsoil only, more than one horizon or the whole soil profile. This is linked to the choice (Input 10) of one humus fraction or two. For reasons discussed on p.61, consideration of the topsoil only is recommended. If the topsoil is less than 20 cm, alter the default value. Thus **Topsoil depth** and **Soil depth considered** need not be the same value, but it is recommended that they normally should be.

Initial carbon as a percentage, and bulk density, are entered for the topsoil and subsoil, where 'subsoil' refers to the average for all subsoil horizons falling within the depth considered. If only the topsoil is being considered, questions on the subsoil may be ignored. Default values for carbon are dependent on climate and texture, but should normally be replaced by data from soil analysis. Data for soil bulk density are rarely given, and the defaults are typical values. The model then displays a basic value used in SCUAF, the mass of carbon in the soil depth considered.

For the nitrogen cycle, the **initial nitrogen in topsoil** (percent) and **initial soil nitrogen** (kg/ha) are calculated from carbon values given above and a hidden default carbon: nitrogen ratio, namely 10:1 for most soils and 15:1 for soils with a strongly acid reaction and/or poor drainage. The user should change the default values displayed by entering **the nitrogen percentage** from soil analysis.

6 SOIL EROSION

The predicted rate of soil erosion is estimated using a modified version of the universal soil loss equation (Wischmeier and Smith, 1978):

Erosion (kg/ha/yr) = Climate factor x Soil erodibility factor x Slope factor x Cover factor x 1000

The factor of 1000 is added to convert the original equation in tonnes per hectare to the kilogrammes per hectare used in SCUAF. The Support Practices factor in the original is omitted, since the agroforestry system itself may provide such support.

> The original version of the equation was based on non-metric units, giving erosion in tons per acre. SCUAF requires the metric version, which gives erosion in tonnes (converted to kilogrammes) per hectare. The Climate and Soil erodibility factors differ between these versions. If using published estimates of the factors, be sure these are for the metric version.

For estimating erosion, users will have widely different levels of data available. In some cases there will be measured data from experimental plots or locally determined estimates of the factors of erosion. Where this is not so, approximate estimates based on readily available data will be needed.

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

Table 18. Generalized values of the soil erodibility factor (FAO, 1979).

		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 19. Generalized values of the slope factor. Based on Wischmeier and Smith (1978).

Slope		*Slope Length (m)*		
Percent	*Degrees*	*50*	*100*	*200*
2	1	0.20	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

CLIMATE FACTOR

- Calculate from meteorological records.
- Obtain from published maps, based on records.
- 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.

SOIL ERODIBILITY 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.
	-	Estimate the erodibility of the soil in qualitative terms as low, medium or high, and use values taken from Table 18.
	-	The model gives default values based on soils of moderate erodibility in Table 18.
SLOPE 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 19. Where not known to the contrary, 100 metres may be taken as a standard slope length.
	-	The model gives default values for the slope classes given in FAO (1979), assuming 100 metres slope length.
COVER 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 20)
	-	The default values are based on FAO (1979).

The model now calculates values for erosion under a 100% cover of the tree component and of the crop component, and displays them. If measured data are available, the user may change these values.

The **Tree proportionality factor** is a special feature of agroforestry systems. It is a measure of the extent to which total erosion in the system is controlled by the tree component (p. 58). The default value of 0.8 is a guess, to be revised as data become available. Using this factor, the model calculates erosion in Year 1 under the specified agroforestry system. If the rate of erosion under the system has been measured, this should be substituted. SCUAF will use the new value entered as the basis for predicting changes in erosion in the future.

> If such a substitution has been made, and you pass through the erosion inputs again, the model will revert to the rate calculated from the factors of erosion, requiring you to re-enter the measured rate.

7 PLANT GROWTH

Basic to the SCUAF model are the rates of **Net primary production** of the Tree and Crop components, and the portioning of this growth between four parts of these plants:

Leaf (herbaceous material)
Fruit (reproductive material)
Wood (above-ground woody material)
Root (below-ground material)

Table 20. Generalized values of the cover factor.

A. Based on FAO (1979)

	Percentage ground cover					
	0-1	1-20	20-40	40-60	60-80	10-100
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		
	Humid	Subhumid	Semi-arid
Crops	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

Users will usually have data on above-ground plant biomass production, so this is the first question asked. Root data are (regrettably) less often available, and default values are set at 0.4 times above-ground production. The net primary production is then apportioned between Leaf, Fruit, Wood and Root; default values refer to a typical cereal crop and fast-growing multipurpose tree, but observed data should normally be substituted. The unit is plant dry matter (DM), not fresh plant material; for some crops, this will require correction of figures for harvested products.

The data entered refer to net primary production from a hypothetical area with 100% cover of tree and crop components respectively. Where data are derived from monocropping, tree-only trials, or a rotational agroforestry system, these are entered directly. If, however, the data come from a spatial agroforestry system, they must be corrected by dividing by the proportional areas covered, for example:

Hedgerow intercropping: 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

The values entered as net primary production are then:
tree, 4000/0.2 = 20 000 kg/ha/yr
crop, 6000/0.8 = 7 500 kg/ha/yr

Values calculated from an agroforestry system will often not be the same as those observed in pure stands. Rates of growth obtained from the agroforestry system under consideration should be given priority. It is recognized that this convention is inconvenient in some cases, but a decision had to be made one way or the other.

> This is probably the most dangerous possible cause of misunderstanding among the inputs, and it is essential to appreciate the convention that is followed.

Where the crop is herbaceous, Crop wood will be zero. It is included to allow for tree crops, e.g. coffee.

Problems arise where the harvested part of a plant is not the fruit, e.g. root crops, tea. It does not matter what interpretation is adopted so long as this is kept consistent with questions (below) on which parts of plants are harvested. It may often be more convenient to designate all harvested parts as 'Fruit', even if this is botanically incorrect. Where there is more than one tree species, their growth rates must be averaged and entered as 'Tree'. Where two or more crops are grown, either as intercrops or two crops per year, enter the total biomass of both crops.

It is possible to treat grass as the crop, but the model has not been tested for this and some of the default values, particularly for roots, will be inappropriate.

The next set of questions refers to the parts of each plant that are **retained as growth**. This means the biomass carried forward in the standing plant from one year to the next. SCUAF keeps a record of the progressively increasing plant biomass. Default values refer to a deciduous tree and an annual crop. Amounts retained as growth will be different in a **cutyear**. Frequently, the whole plant will be harvested or burnt, and the roots will die and pass into the soil; but in coppicing. For example, some proportion of the woody stem and roots will be retained in the plant.

The proportion of roots that are **coarse roots** is needed for calculating the delay in transfer of root residues to the soil in a cutyear (Input 10). For convenience, 'coarse roots' are defined as all roots which it is supposed will not decay in the year in which they die. Some fraction of roots may grow to **below the soil depth considered** (Input 5), and thus pass out of the plant-soil system being modelled.

The model converts all data on plant dry matter into plant carbon, using a default proportion of 0.5 unless analyses are available. For the nitrogen cycle, values are requested for the carbon:nitrogen ratios of each plant part; if the user has plant tissue analyses giving nitrogen as a percentage of plant dry matter, these should be converted into carbon:nitrogen ratios.

8 ADDITIONS

Additions to the plant-soil system may be organic or inorganic. They are entered separately for each **Period** specified for the system (Input 4).

Organic additions refer to farmyard manure, compost or mulch of external origin. These are treated in the model as an addition to plant litter. Note that inputs are required in terms of dry matter, which will frequently require conversion from the data available; for example, farmyard manure consists of about 30% dry matter, so 1 tonne of manure is entered as 300 kg DM. Enter carbon and nitrogen fractions in the organic additions.

Have you fed tree fodder or crop residues to livestock and returned the manure to the soil? Since not all the manure derives from the residues, SCUAF treats these as flows external to the system. Thus, include the plant residues that are fed to livestock as harvest, and enter the manure returned as organic additions.

Inorganic additions refers to nitrogen in fertilizer. Weight of fertilizer and its nitrogen fraction are asked for, but if original data are as kg nitrogen, enter the fraction as 1.0.

9 REMOVALS

Removals (harvest, etc.) from the plant-soil system are an important element of SCUAF. Soil changes will usually differ appreciably if one plant part is removed rather than returned to the soil.

Fractions harvested are entered for each plant part, separately for annual harvests and for the cutyear (p.54). The default assumes that the crop fruit is harvested annually and the tree wood in a cutyear. Note particularly that the default value assumes that crop leaf, i.e. residues, remain on the soil; you must alter this where necessary.

A prompt then asks if there are any losses from the plant-soil system, other than harvest. This is intended to cover losses that are not harvested, e.g. burning in shifting cultivation. If the answer is 'Yes', details are requested.

Be careful to ensure that for any plant part, the sum of annual harvest, cutyear harvest and other losses does not exceed 1.0. For cutyears, the values required are **additional** fractions harvested. If, for example, 0.2 of the tree wood is harvested annually and all that remains in the standing tree is harvested in the cutyear, enter the additional cutyear harvest as 0.8, not 1.0. During a cutyear, accumulated growth is added to the annual litter. The model is not proofed against harvest exceeding the entire growth, and will treat mistakes as 'negative litter'.

10 SOIL PROCESSES

The soil processes group of inputs covers the processes involved in the conversion of plant litter to soil humus, the decomposition of humus and nitrogen cycling. It is a critical part of the model, since changes in value of some variables can have a large effect upon the outputs. This is where a particular model can be adjusted to fit specific experimental data, by adjusting the rates of selected processes.

Users who are not soil scientists, however, may wish to make use of the default values for processes. These are best estimates, based on published research, for the climate, soil texture and drainage specified in Input 3.

A. THE CARBON CYCLE

As outlined on p.59, the model treats carbon cycling in two stages: **conversion losses** or humification, the conversion of plant litter to soil organic matter; and **humus decomposition**, the loss of soil organic matter through bacterial oxidation.

Conversion losses are the fractions of plant litter carbon lost, through oxidation, during its conversion to soil humus. In isotope labelling studies, this is the rapid loss of carbon that takes place, in the tropics, during approximately the first six months after litter is added to the soil. The default values for medium-textured soils are mid-points in the estimates of Nye and Greenland (1960), 0.85 for above-ground residues and 0.67 for roots; organic additions are also set at 0.67. This means that for above-ground plant residues, 85% of the carbon is lost through oxidation and 15% converted to humus, whilst for roots and organic additions, 67% is lost and 33% converted. Following the model of Parton et al. (1987), which in turn makes use of experimental data from Sorensen (1981), default values are set slightly higher for sandy soils and lower for clays.

The next questions cover the delay in decomposition of coarse roots. It is unlikely that all coarse roots decompose in the same year that a tree is cut. The defaults assume that of those roots defined as coarse in Input 7, 75% decay one year later and 25% two years later. This has the effect of damping the peak in soil carbon input that would otherwise occur in cutyears.

For **humus decomposition**, the first question is whether the user wishes to model one humus fraction or two. For reasons discussed on p.61, it is recommended that for most modelling, the assumption of one humus fraction should be made, in conjunction with taking the soil depth considered as the topsoil only (Input 5). If deeper soil horizons are included, then it is more appropriate to assume two humus fractions.

For the one-fraction assumption, the **humus decomposition constants** for lowland climates are set by default at 0.03 under trees and 0.04 under crops. These are the values for forest and cropping respectively first found by Nye and Greenland (1960), and broadly confirmed by subsequent research including isotope-labelling studies. For agroforestry systems, SCUAF assumes that the net rate is proportional to the areas under trees and crops. Thus for a tree cover of 0.4, a crop cover of 0.6 and the above default values, the humus decomposition constant for the system would be:

$$(0.4 \times 0.03) + (0.6 \times 0.04) = 0.036$$

Values for cooler, highland climates are set at lower rates.

For the assumption of two humus fractions, the above values refer to labile humus. For stable humus, almost no experimental evidence exists on which to set default values. The default assumptions set low rates for its decomposition constant, and for the annual transformation of labile to stable humus. It is further assumed that 0.67 of the total initial humus is in stable form, and that no plant litter is directly converted to stable humus, but users can change these assumptions. The overall effect of the default values is that very little change occurs in stable humus!

B. THE NITROGEN CYCLE

Inputs for the nitrogen cycle cover inputs, outputs and internal transfers within the system. The assumptions underlying the model are discussed on p.62. Default values are taken from a review of published results.

The rates of **symbiotic fixation** are requested per unit area under nitrogen-fixing trees and crops. This means the fixation (kg N/ha) that would occur if the area were entirely covered by the nitrogen-fixing proportion of trees or crops respectively. These rates are adjusted, within the model, for the fractional areas under trees and crops and the proportions of each that are nitrogen-fixing. If, therefore, experimental data have been obtained from an agroforestry system, the measured fixation must be divided by the fractional area under the plant concerned (as in the convention for plant growth, pp.79-80). The default values, 100 kg N/ha/yr, are for a fairly high rate of fixation, and should be altered on best evidence for the trees and crops concerned. A low proportion, 0.1, of the symbiotically fixed nitrogen is assumed to slough off into the soil humus, the remainder directly entering the plants.

Similar questions follow for the rate of **non-symbiotic fixation. Atmospheric inputs** are nitrogen entering the system dissolved in rainfall and as blown dust. **Throughfall and stemflow** are treated as an internal transfer, subtracted from litter nitrogen and added to soil mineral nitrogen.

The above processes are combined with mineralization of nitrogen from plant litter and soil humus to produce a pool of available mineral nitrogen. The approach is to take this pool, estimate losses and assume that the remainder is taken up by plants. Information is requested on the fractions of available mineral nitrogen lost by **leaching gaseous losses** (denitrification and volatilization) and **fixation onto clay minerals**. There is evidence that leaching losses are lower under trees then crops, and the default values are set accordingly. The model multiplies these values by the fractional areas under each component to obtain the rate of leaching under the agroforestry system. Thus, the presence of trees reduces nitrogen leaching losses. Leaching of nitrogen of fertilizer origin is assumed, by default, to be faster than that derived by mineralization of organic nitrogen. Default values for rates of leaching are set by climate, soil texture and drainage.

11 SOIL-PLANT FEEDBACK FACTORS

The feedback factors represent the effects of changes in soil properties on rates of plant growth. If the soil is degraded, by loss of organic matter, nitrogen or profile depth, the rate of plant growth will be reduced, and *vice versa*. Of several possible methods of modelling such feedback, that selected is to assume that a **relative change in initial values**, of soil carbon, nitrogen and depth, causes a **proportional change** in plant growth. The feedback factors represent these properties. Thus for carbon:

$$NPP_t = NPP_1 \times (C_t/C_0) \times F_c$$

where NPP_t and NPP_1 are rates of net primary production in years t and 1 respectively, C_t is soil carbon in year t, C_0 is initial soil carbon, and F_c the carbon feedback factor. A feedback factor of 1.0 means that a given increase or decrease in a soil property, relative to its initial value, causes the same relative change in plant growth. A feedback factor of 0.0 means that plant growth is unaffected by the soil property concerned.

The starting point for setting the default values was to assume that if carbon and nitrogen were reduced to hypothetical values of zero, growth of crops would cease. That is, 100% reduction in both carbon and nitrogen would reduce crop growth by 100%, a combined feedback factor of 1.0. This is distributed between carbon and nitrogen, giving default crop-feedback factors for each of 0.5. Trees, with their deeper rooting systems, are assumed to be less affected than crops by soil degradation, and assigned default feedback values of 0.25. For soil depth, the assumption of a linear reduction in crop growth with decrease in soil profile depth is one commonly made in early attempts to model the effects of erosion.

Very little experimental evidence is available on which to base feedback factors, and research is needed. For nitrogen feedback, there may be indirect evidence from fertilizer trials: if 1 kg nitrogen added as fertilizer produces a certain growth response, then the effect of an extra 1 kg nitrogen of organic origin is likely to be equal or greater. It is quite possible that in some circumstances feedback factors may exceed 1.0.

> If high feedback values for both carbon and nitrogen are selected in rotational systems, an accelerating oscillation effect may be produced, with plant growth rising and falling to unrealistic values.

REVIEWING THE INPUT DATA

Having completed a set of inputs, it is recommended that these should be reviewed to eliminate mistakes or inconsistencies. This review is best done away from the computer. The recommended sequence of actions after completing inputs is:

1. Enter 99 to exit from the Input Menu.
2. Select 3 to enter the Utilities Menu.
3. Select 1 and save the model (see p.95).
4. Select 99 to exit from the Utilities Menu.
5. Select 2 to enter the Output Menu.
6. Place the computer on printer output and obtain Outputs 1 and 2, Documentation and Data.
7. Exit, **go away from the computer**, and thoroughly review the input data.

The Output Menu (Table 21)

Outputs are in a logical sequence but, as with inputs, each output procedure is independent so they can be selected in any order. In particular, having entered one complete set of inputs, it is possible to move freely between the Input and Output Menus, changing the values of one or more inputs and examining the effects.

Screen, printer and graphical outputs

Outputs are initially to the screen. By the usual DOS practice of pressing CONTROL + P they can be directed additionally to the printer. Pressing CONTROL + P again restores output to the screen alone.

Pressing CONTROL + S temporarily halts screen output to allow viewing of data that would otherwise scroll off the screen. The same keys cause output to be resumed.

Graphic outputs are explained on p.92 but a word of advance warning may be given. If you produce the same output, e.g. changes in soil carbon, twice under the same file name, the second output will over-write the first. So for successive outputs of the same kind for which you require graphs, change the file name (Input 1).

1 DOCUMENTATION

Select Output Menu 1, Documentation, and you will get a reproduction of the Documentation input. It is recommended that this should be used as a form of heading, preceding any other set of outputs to the printer.

2 DATA

This output gives the complete set of input data. Two derived variables are included: values of the humus decomposition constant and nitrogen leaching for the agroforestry system as a whole. This output should normally be directed to the printer as it scrolls off the screen. Whilst it is possible to halt scrolling by pressing CONTROL + S, a better way to inspect data on the screen is by using the Inputs.

Before proceeding with other inputs, it is strongly recommended to:

- Complete a set of inputs
- Save the model (p.95)
- Obtain outputs 1 and 2 on the printer
- **Carefully check this printout for errors and inconsistencies**

Table 21. The SCUAF Output Menu.

OUTPUT MENU	
INPUT CONDITIONS	
1 -	Display Documentation
2 -	Display Data
3 -	Display Agroforestry System
EROSION	
4 -	Display Changes in Erosion
TOTAL CARBON AND TOTAL BIOMASS	
5 -	Display Changes in Soil Carbon
6 -	Display Changes in Total Biomass and Carbon
NITROGEN	
7 -	Display Changes in Soil Organic Nitrogen
8 -	Display Changes in Soil Mineral Nitrogen
9 -	Display Changes in Plant-Soil System Nitrogen
PLANT GROWTH AND HARVEST	
11 -	Display Changes in Plant Growth
12 -	Display Changes in Harvest
20 -	Graph Outputs
99 -	Exit from Output Menu
SELECT FUNCTION (0 = MENU)	

Time periods: Outputs 3-9, 11 and 12

Outputs 3-9, 11 and 12 display changes over a period of time, asking the user, 'For how many years?' Any value from 1 year upwards may be selected, although at more than 16 years, headings to the tables will begin to scroll off the screen.

For purely spatial agroforestry systems without a cutyear, an output of 5 years is sufficient to show whether the tendency is one of soil improvement, steady state or degradation, whilst 10 years will indicate the magnitude of such changes. Once such a trend is established, the nature of the model is such that it will not be reversed. For spatial systems with a cutyear, the output should be sufficient to include at least two cutyears. For rotational systems, a minimum of two complete land-use rotations should be included.

It is recommended that for most purposes outputs should not exceed 20 years. If soil changes are substantial, the calculated values after such a time will differ substantially from the initial values based on experimental data or best estimates. There may be exceptions where it is wished to examine the long-term effects of gradual trends, or to model long rotations such as are found in some forms of taungya or in forestry.

For all yearly outputs Column 1, headed TIME or T, shows the Year. Where necessary, there is an additional top line, headed INIT, showing the initial state of the system. The following convention is followed.

Outputs which refer to a process, or something which has happened during the year, e.g. erosion, plant growth, harvest	Output tables show for Year N what took place during Year N
Outputs which refer to a state, e.g. soil carbon	Output tables show for Year N the state at the end of year N

3 AGROFORESTRY SYSTEM

This output converts the Periods of the input into year-by-year form, giving for each year:

AREA UNDER TREE	Fraction of land area under the tree component
AREA UNDER CROP	Fraction of land area under the crop component
CUTYEAR	Whether it is a cutyear, as Y = Yes, N = No

4 EROSION

Outputs 4 - 9 display modelled changes in the soil properties over the number of years selected. The first of these is changes in erosion. Meanings of columns are as follows:

5 CLIMATE FACTOR SOIL FACTOR SLOPE FACTOR TREE COVER FACTOR CROP COVER FACTOR	Causative factors in the soil loss equation (see Input 6)
SOIL EROSION	Soil erosion (kg/ha/yr)
C EROSION	Carbon erosion (kg C/ha/yr), calculated from soil erosion, topsoil carbon content and the carbon enrichment factor
N EROSION	Nitrogen erosion (kg N/ha/yr), similarly calculated
SOIL DEPTH	The total depth of soil remaining after erosion (cm)

In accordance with the convention stated above, the values for the factors of erosion and for soil depth show states at the end of the year indicated, whilst the erosion is that taking place during the year indicated.

Outputs for Years 2 onwards show how erosion is changing with time. This is calculated from changes in the causative factors, corrected where necessary by the same relative correction which the user entered for Year 1. The Climate and Slope factors remain constant. The Soil factor rises or falls with decrease or increase, respectively, in soil organic matter. The Cover factors rise or fall with decrease or increase in rates of plant growth. A higher value for a factor of erosion means more erosion.

The ratios between erosion of soil, carbon and nitrogen do not remain constant. If a soil is impoverished in carbon, a given amount of eroded sediment will contain proportionally less carbon, and similarly for nitrogen.

5 SOIL CARBON

The prediction of changes in soil organic matter, as represented by carbon, was the original aim of the SCUAF model and remains its most fundamental output. The functioning of the model is such that when soil carbon increases, erosion is reduced and the nitrogen supply to plants is nearly always increased. If soil carbon decreases, then erosion becomes faster and the nitrogen supply diminishes. This represents a basic hypothesis that maintenance of soil organic matter is the primary requirement for soil conservation and sustainable land use.

TOTAL	Soil humus carbon at the end of the year (kg/C/ha)

For the following gains and losses, the unit is kg C/ha/yr.

GAINS:	
HUMIFICATION	Carbon entering the soil from humification of plant residues (above-ground litter plus root residues)
ADDITIONS	Carbon entering the soil from humification of organic additions
LOSSES:	
OXIDATION	Oxidation loss obtained as soil carbon at the end of the previous year multiplied by the humus decomposition constant for the system
EROSION	Loss of carbon in eroded sediment, repeated from Output 4

For the two-fraction assumption, the output automatically changes. Columns 2-4 show the end-of-year state of labile, stable and total carbon respectively (p.61). The soil carbon gains are the same as for the one-fraction output. The losses show oxidation of labile and stable carbon separately; it is assumed that erosion, being confined to the topsoil, affects only labile carbon. Column 7 shows the transformation of labile into stable carbon.

Changes in soil carbon (or, under the two-fraction assumption, labile carbon) are the basis for the carbon feedback effect upon plant growth.

6 TOTAL BIOMASS AND CARBON

This output shows the changes in carbon present in the plant-soil system as a whole. Where there are growing trees, organic matter is accumulating in these, giving a build-up of carbon in the system as whole although this may not be reflected in the soil.

CURRENT PLANT BIOMASS (kg DM/ha):

TREE	The biomass of the accumulated growth, after harvest,
CROP	litter fall, etc.); values for annual crops are zero.
TOTAL	

PLANT-SOIL SYSTEM CARBON (kg C/ha):

PLANT	The carbon in the accumulated growth, obtained by multiplying the above outputs by their carbon fractions (default 0.5)
SOIL	Soil carbon, repeated from Output 5
TOTAL	Total carbon in the plant-soil system

This output can be used to show the consequences of whole-tree harvesting as compared with partial harvest and return of residues.

7 SOIL ORGANIC NITROGEN

This and the three following outputs cover the nitrogen cycle (Figure 15, p. 65). Units are kg N/ha for states and kg N/ha/yr for rates.

Output 7 matches, for soil nitrogen, Output 5 for soil carbon. It differs according to the one- or two-fraction humus assumptions.

For **one-fraction humus**, meanings of columns are as follows (Figure 15A):

TOTAL	Total soil nitrogen
GAINS:	
FIXATION	That part of atmospheric nitrogen fixation, symbiotic and non-symbiotic, which enters the soil organic matter
HUMIFICATION	Nitrogen entering soil organic matter through humification of plant residues
ADDITIONS	Nitrogen from organic additions
C:N RATIO	The soil carbon:nitrogen ratio at the end of the year, obtained from the total carbon and total nitrogen.
LOSSES:	
MINERALIZATION	Mineralized organic nitrogen
EROSION	Eroded nitrogen, from Output 4

For the **two-fraction** humus assumption, columns and their headings are similar to above except that the nitrogen contained in labile and stable humus, and the respective oxidation losses, shown separately.

8 SOIL MINERAL NITROGEN

Soil mineral nitrogen shows the feature of greatest interest from the point of view of plant growth, changes in the available mineral nitrogen and the amount reaching plants. Units for all columns are kg N/ha/yr. Meanings of columns are as follows (Figure 15B):

GAINS:	
LITTER MINERALIZATION	Mineral nitrogen derived from mineralization of plant residues (litter and roots)
HUMUS MINERALIZATION	Mineral nitrogen derived from mineralization of decomposing soil organic matter
CONSTANT The sum of:	- atmospheric inputs - throughfall and stemflow - that part of non-symbioticfixation which becomes mineral nitrogen
ADDITIONS The sum of:	- nitrogen in organic additions - nitrogen in fertilizer
TOTAL AVAILABLE	The total available mineral nitrogen in the year concerned, obtained by summing the above gains
LOSSES:	
LEACHING	The sum of leaching of nitrogen of organic origin and leaching of fertilizer nitrogen
OTHER	The sum of gaseous losses and net fixation onto clay minerals
PLANT UPTAKE	Available soil mineral nitrogen minus the sum of losses
SYMBIOTIC FIXATION	That part of symbiotically fixed nitrogen which enters the plants directly
SUM TO PLANTS	The total nitrogen reaching the plants; the sum of plant uptake from the soil and direct uptake from symbiotic fixation

SCUAF does not partition nitrogen uptake between the tree and crop components.

Changes in the sum to plants are the basis for the nitrogen feedback effect upon plant growth.

9 PLANT-SOIL SYSTEM NITROGEN

Plant soil system nitrogen gives nitrogen flows external to the plant-soil system and their net effect (Figure 15C). Units are kg N/ha/yr.

GAINS:	
CONSTANT	The sum of atmospheric inputs and non-symbiotic fixation
SYMBIOTIC FIXATION	Symbiotic fixation by tree and crop
ADDITIONS	The sum of nitrogen in organic additions and nitrogen in fertilizer
TOTAL GAINS	The sum of the above
LOSSES:	
HARVEST	Nitrogen in harvested plant parts
BURN ETC.	Nitrogen in other losses, e.g. burning
EROSION	Nitrogen in eroded sediment
LEACHING	Leaching of mineral Nitrogen (of organic origin plus from fertilizer)
GASEOUS	Denitrification and volatilization
TOTAL LOSSES	The sum of the above
NET GAIN/LOSS	Total system gains minus total system losses, shown as negative for net losses,

10 MINERAL NITROGEN BALANCE CHECK

The purpose of the mineral nitrogen balance check output is to check the internal balance of the nitrogen cycle. For three subsystems within the model--litter nitrogen, soil organic nitrogen and mineral nitrogen--inputs and outputs are necessarily balanced. There is, however, no automatic equality between the nitrogen contained in the annual plant biomass increment and that calculated as taken up by plants, from soil mineral nitrogen plus symbiotic fixation.

This absence of any inbuilt balancing mechanism is intentional. The user has entered rates of plant growth and the nitrogen content of plant material, thereby specifying the nitrogen entering the plants in one year. Where data are available, this will be based on measured rates of growth and plant tissue analysis, and so can be expected to be reasonably accurate. The various components of the nitrogen cycle have also been entered, from which the supposed nitrogen supply reaching the plants has been calculated. Whilst parts of this may be based on experimental data, there will nearly always be values which are estimates, e.g. leaching, gaseous losses. For incomplete or simulated data, such as may be used in training exercises, many of the input values may be estimates.

This output allows the model to be adjusted so that it becomes internally consistent. It displays, for Year 1:

Nitrogen content of plant biomass increment:
Total nitrogen uptake by plants:

If the nitrogen in the plant biomass increment is greater than the calculated nitrogen uptake, then either the nitrogen stated as contained in the plant growth is too high or the calculated uptake too low, and *vice versa.*

The nitrogen content of the plant biomass increment can be altered by changing:

- rates of plant growth
- carbon:nitrogen ratios of plant parts

The nitrogen uptake by plants can be altered by changing:

- rates of nitrogen fixation
- fertilizer nitrogen
- rates of leaching
- other nitrogen gains or losses.

It is up to the user to decide where the greatest sources of uncertainty lie, and adjust values until an approximate balance is obtained.

11 PLANT GROWTH, AS AFFECTED BY SOIL

The output of plant growth shows the effects of soil changes upon plant growth. Units are kg DM/ha/yr.

The effect on growth is determined by the direction and magnitude of changes in soil carbon, nitrogen and depth, together with the feedback factors. The headings are self-explanatory: the annual biomass production of the leaf, fruit, wood and root components of the tree and the crop, with the last column showing the total plant biomass production in the system.

It should be made clear that **this is not a prediction of future plant growth,** but only an estimate of the effects of changes in soil properties. Plant growth in an agroforestry system is affected by many other factors, such as the irregular variations in rainfall, pests and diseases, or changes in the availability of inputs. A predictive analysis of any system needs to take all such factors into account. SCUAF only estimates the consequences of changes to the soil.

12 HARVEST

This output the harvested products from the system, as specified in Input 9. These can include the tree leaf (fodder), fruit and wood, and the crop leaf (harvested residues) and fruit (grain, etc.). Both the annual harvest (e.g. crop fruit) and the additional cutyear harvest (e.g. tree wood) appear. Units are kg DM/ha/yr; where the crop fruit is conventionally given in other units (e.g. tubers with water, fresh fruit or green leaf) the user must make an adjustment.

20 GRAPHICAL OUTPUTS

To make use of the graphics facility, the instructions for installation given on p.14 must have been followed. Users without a hard disk and/or the Lotus program cannot use the SCUAF graphics facility, but may still be able to graph the outputs using their own graphics program (p.108).

To produce a graph, the output must first have been obtained as a table. The most recent output under a given FILENAME will be stored. On selecting 20 - Graph Outputs, the following prompts will appear:

Select the required Job

A list of TITLES of available runs appears. Move the highlight using up-down arrow keys and select by pressing RETURN.

Select the required Output

If they have been run under the selected FILENAME, Outputs 3-9, 11 and 12 are listed. Select one as above.

Select Y-variables

The X-axis on all graphs is Years. Up to 0 variables, or columns in the output tables, may be graphed. Move the highlight using the up-down arrow keys, select highlighted variables by pressing RETURN, then quit by pressing function key F10.

Select Graph Type

Line graphs have been found satisfactory for Outputs 3-9, bar charts for Outputs 11-12. Select by moving the highlight and pressing RETURN.

Select type of scaling

Automatic scaling means that the range of values fills the graph from top to bottom, and manual scaling is generally more satisfactory. If manual is selected, the user is asked:

Enter lower Y value	This will usually be 0, but higher or negative values can be entered
Enter upper Y value	Enter a number that is clearly above the highest value to be graphed

On entering this last value (or immediately if automatic scaling is selected) a graph appears. SCUAF loads Lotus, imports the relevant output file, sets graphic parameters and displays the graph. The first title is the TITLE of the model, whilst the second is the variable(s) graphed. To return to the Output Menu, press any key.

To print graphs

To obtain a printed graph, the selected output may be imported into a graph-plotting program, a graph produced, saved and printed. The most recent outputs under any given file name are stored in the drive and directory specified under Utilities Menu 3, by default in C:SCUAF\OUTPUT.

If the user possesses the Lotus program and is using it to produce graphs, then printed graphs can be obtained using the Lotus Printgraph function. In this case, proceed as follows:

1. Obtain the data as a tabular output.

2. Obtain a graph, using Output Menu 20.

3. On exiting from this graph, select L(otus); this will put you in Lotus 1-2-3, with the graph just obtained as the current graph.

4. Using Lotus Version 2.0, the sequence of commands leading to production of printed graph is as follows. You must first have created a subdirectory C:\SCUAF\GRAPH.

\	Brings Lotus Menu onto screen
G	raph
N	ame
C	reate
GRAPHNAM	Enter the graph name
S	ave
C:\SCUAF\GRAPH\GRAPHNAM	Saves the graph in the subdirectory C:\SCUAF\GRAPH
Q	uit
Y	es

This returns you to the SCUAF Output menu.

For the graph name, it is necessary to modify the SCUAF file name. This is because a graph name is stored in the form GRAPHNAM.PIC, where the extension is always .PIC, and so the kind of output (carbon, erosion, etc.) must be included in the first eight characters. Here is a suggested systematic way of naming graphs. The first five characters must be unique for any SCUAF model.

Output			*File name with extension*	*Graph name*
3	Agroforestry system		FILENAME.SYS	FILENSYS
4	Erosion		FILENAME.ERO	FILENERO
5	Soil carbon:	1-fraction	FILENAME.CA1	FILENCA1
		2-fraction	FILENAME.CA2	FILENCA2
6	Total biomass and carbon		FILENAME.TOT	FILENTOT
7	Soil organic nitrogen:			
		1-fraction	FILENAME.NI1	FILENNI1
		2-fraction	FILENAME.NI2	FILENNI2
8	Soil mineral nitrogen		FILENAME.MIN	FILENMIN
9	Plant-soil system nitrogen		FILENAME.SYN	FILENSYN
11	Plant growth		FILENAME.GRO	FILENGRO
12	Harvest		FILENAME.HAR	FILENHAR
File names ending in 1, 2, ..			FILENAM1.SYS	FILE1SYS
			FILENAM2.SYS	FILE2SYS

To obtain one or more printed graphs:

- Repeat the above procedure, Steps, 1-4, for all the graphs that you wish to save; then exit from SCUAF.
- Load Lotus Printgraph, by entering the Lotus subdirectory and typing PGRAPH.
- Set the Graphs Directory to C:\SCUAF\GRAPH.

- Choose Image-select, and mark the graph(s) you wish to print by moving the highlight to them and pressing the space bar.
- Select G(o) to print the graph(s).

A note on Lotus 1-2-3

The SCUAF graph-plotting procedure creates a file AUTO123.WK1 in the LOTUS subdirectory. In order to use Lotus subsequently for other purposes, you must erase this file from the LOTUS subdirectory. To do this, type:

C.D\LOTUS	Change to Lotus subdirectory
ERASE AUTO123.WK1	Erases file

Do not erase AUTO123.WK1 from the SCUAF subdirectory.

The Utilities Menu

Table 22. The SCUAF Utilities Menu.

```
U T I L I T I E S  M E N U

 1  -  Save current model
 2  -  Load a model
 3  -  Set default data drive and/or directories
 4  -  Clear current model

99  -  Exit from utilities menu

SECT FUNCTION (0 = MENU)
```

1 SAVE CURRENT MODEL

Choosing this option from the Utilities Menu brings up the statement that the model currently in the memory will be stored under whatever file name is currently in use. Simply press the RETURN key and the complete model will be stored under this file name.

> This will over-write any model previously stored under the same file name. If you do not want this to happen, go to Input Menu, 2 -Documentation, and alter the file name.

2 LOAD A MODEL

To load all data from any previously stored model, enter the FILENAME of the model you require. Go to the Output Menu, 1 - Documentation to check that the model you wanted has been loaded.

If you type in the file name of a model that has not been stored, a screen prompt appears listing the models available.

3 SET DEFAULT DATA DRIVE AND/OR DIRECTORIES

Unless entered otherwise, the data of models that have been run are stored in C:\SCUAF\MODEL and the outputs in C:\SCUAF\OUTPUT. You may change these, e.g. by directing models and/or outputs to a diskette.

4 CLEAR CURRENT MODEL

This function clears the memory and sets all variables to their initial values. It is equivalent to exiting from SCUAF and re-loading.

> **If you are running two models during the same SCUAF session, it is essential to clear the first before entering the second.**

This is because some of the default values are initialized to -1 (minus 1), which has the effect that they will be internally calculated the first time an input is entered, but left unchanged if this input is entered again, so allowing the user to alter them without this alteration being rescinded (p.108).

DISASTER SITUATIONS AND CRASHES

SCUAF is programmed to function realistically within the range of conditions normally to be expected in land use systems. If certain variables are set to unusually high or low values, then in feedback effects may lead to exponential growth or decline, ending with a 'crash'. On any of the outputs, values are produced for a number of years, followed by an error message and exit from the model. This is most likely to happen with:

- very high values of erosion (>100 000 kg/ha/yr);
- high values of one or more feedback factors (>2.00).

There are two types of model crash:

1. Soil carbon and plant growth rates are steadily increasing. With high feedback effects, this growth can become exponential, leading to numbers greater than the computer can contain.

2. Owing to rapid soil degradation, plant growth is reduced to zero. When this happens, the error 'division by zero' occurs.

The first of these types is an artificial situation, the result of allowing feedback effects to reach unrealistic levels. The second, however, can represent a real-world disaster situation, in which erosion has reached several hundred tonnes a year and plant growth has become impossible. Because of the very high values of erosion on steep slopes predicted by the universal soil loss equation, this situation occurs even with the default values if the environment is set to a steep slope in the humid tropics.

Data produced up to the year of a model crash is stored as an output. By reloading SCUAF, entering the Output Menu and asking for 20 - Graph outputs, a disaster situation can be seen graphically.

TO QUIT

Having completed one or two models and runs, return to the Main Menu by selecting 99 in the Output (or other) Menu, and exit by selecting 99 on the Main Menu. A prompt will ask whether you wish to save the current model, that is, the run of the model with the most recent alterations. If you have already saved it through the Utilities Menu, there is no need to do so again.

7 MODELLING DIFFERENT LAND USE SYSTEMS ON SCUAF

Agroforestry technologies

An agroforestry technology is a distinctive arrangement of agroforestry components (trees, crops, pastures, livestock) in space and time. An agroforestry system is a specific local example of a technology, characterized by environment, plant species and arrangement, management, and social and economic function. There are thousands of agroforestry systems but only some 20 distinct technologies. These are shown in Table 23, classified according to the components present and the nature of their spatial or temporal arrangement.

The last two technologies listed, combinations of trees with insects or fisheries, are too specialized in nature to be relevant for treatment on SCUAF. The remainder can be modelled, using the method employed in Input 3, in the ways indicated below. Examples are given in Table 24.

Shifting cultivation

Periods of cropping alternate with periods of natural woody fallow, in a fully rotational system. In the last year of the fallow, it is felled and (usually) burnt. In representing this system, it is necessary to start with a fallow period, so that the accumulated biomass (especially root biomass) of the fallow is built up in the model. Taking as an example a pattern of 3 years cultivation alternating with 12 years of fallow, shifting cultivation can be represented as:

Period	*Years*	*Area under tree*	*Area under crop*	*Cutyear*
1	11	1.0	0.0	No
2	1	1.0	0.0	Yes
3	3	0.0	1.0	No

Period 1 returns automatically after the last period specified. The loss of above-ground plant material in burning during the cutyear (which is not necessarily complete) is specified under the Other losses section of Input 9. An example is given on p.16.

Improved tree fallow

This is also a purely rotational system, but the fallow consists of planted trees. The trees may be planted purely for the purpose of soil improvement, or combined with partial harvest (e.g. of the larger woody parts). Representation in SCUAF is through the same sequence of three periods as in shifting cultivation above. The difference is in the growth rate of the trees, and the fact that cutyear removals are as harvest instead of burning.

Taungya

Young trees are planted simultaneously with crops. Intercropping continues until the crops have been suppressed by the trees (by shade or root competition), after which the trees grow as a pure forest until they are harvested, usually for timber. The cycle is then repeated.

Table 23. Agroforestry technologies.

MAINLY AGROSYLVICULTURAL (trees with crops)

Rotational:

Shifting cultivation
Improved tree fallow
Taungya

Spatial mixed:

Open: Trees on cropland

Dense: Plantation crop combinations
Multistorey tree gardens

Spatial zoned:

Hedgerow intercropping (alley cropping, barrier hedges) *
Boundary planting
Trees on erosion control structures
Windbreaks and shelterbelts *
Biomass transfer

MAINLY OR PARTLY SYLVOPASTORAL (trees with pastures and livestock)

Spatial mixed:

Open: Trees on rangeland or pastures

Dense: Plantation crops with pastures

Spatial zoned:

Live fences
Fodder banks

TREE COMPONENT PREDOMINANT (cf. also taungya)

Woodlots with multipurpose management
Reclamation forestry leading to multiple use

OTHER COMPONENTS PRESENT

Entomoforestry (trees with insects)
Aquaforestry (trees with fisheries)

* Also agrosylvopastoral.

The gradual suppression of crop growth cannot be entered into SCUAF. However, it can be indirectly represented by making the area under crops decrease progressively during the cropping period. Taking as an example 3 years intercropping followed by 15 years of forest growth, in the last of which the trees are harvested, taungya can be represented as:

Period	*Years*	*Area under tree*	*Area under crop*	*Cutyear*
1	1	0.4	0.6	No
2	1	0.6	0.4	No
3	1	0.8	0.2	No
4	14	1.0	0.0	No
5	1	1.0	0.0	Yes

The timber harvest in Year 18 is shown as a cutyear harvest of (all or most) tree wood.

Trees on cropland

Trees are grown in a sparse, mixed system amid crops. Examples are with *Acacia albida* and with fruit trees, e.g. mango. If it is assumed that the tree litter becomes more or less evenly dispersed over the cropped land, then the system can be specified as one Period, with e.g. 0.2 Area under tree and 0.95 Area under crop. The total sums to more than 1.0 to indicate that part of the crop grows beneath the trees.

Some studies have shown higher soil fertility under tree canopies than beyond them. To model this, make two runs of SCUAF, one with trees and another without, and compare the soil changes.

Plantation crop combinations

The 'plantation crop' refers to the agricultural tree or shrub crop, such as tea, rubber or oil palm. There are two kinds of combination: with (so-called) shade trees above, as in coffee/cacao with *Erythrina/Cordia*; or with herbaceous crops below, as in coconut with pineapple. In both cases the arrangement is spatial, mixed and dense. Either or both 'tree' and 'crop' may be perennial.

In the former type of system, the shade trees become the tree component and the plantation crops, even if they are woody, the crops. In the latter, the woody plantation crops become the tree component. If both components are harvested continuously, then this is a purely spatial system, specified as one period. If either or both components are harvested allat once, say after 10 years, the system might be represented as:

Period	*Years tree*	*Area under*	*Area under crop*	*Cutyear*
1	9	0.6	0.8	No
2	1	0.6	0.8	Yes

The crop may include a woody part. In the case of tea, the crop harvest is a fraction of the leaf.

Table 24. Examples of the specification of agroforestry systems.

Description	Period	Years	Fraction under Tree	Crop	Cut year	Fraction N-fixing Tree	Crop
Improved fallow Maize for 3 years, N-fixing trees for 5 years in last of which felled, then further cropping.	1 2 3	3 4 1	0.0 1.00 1.00	1.0 0.00 0.00	No No Yes	0.0 1.0 1.0	0.0 0.0 0.0
Plantation crop combination. Continuous, close cover of coffee with open canopy of non-N-fixing shade trees, the latter felled and replanted every 15 years.	1 2	14 1	0.25 0.25	0.95 0.95	No Yes	0.0 0.0	0.0 0.0
Hedgerow intercropping. Hedgerow 0.6 m wide, alleys 5.4 m wide, N-fixing hedge species, crop rotation of sorghum with legumes.	1	3	0.10	0.90	No	1.0	0.5
Rotational hedgerow intercropping. Above for 5 years, followed by 3 years' tree fallow, felled in the last year.	1 2 3	5 2 1	0.10 1.00 1.00	0.90 0.00 0.00	No No Yes	1.0 1.0 1.0	0.5 0.0 0.0
Continuous arable cropping. Maize-maize-legume rotation (for comparison)	1 2	2 1	0.00 0.00	1.00 1.00	No No	0.00 0.00	0.00 1.00

Multistorey tree gardens

This is a permanent, dense, mixed system in which many kinds of trees and herbaceous plants are grown together. Harvest is continuous, with no specific cutyear. Home gardens are the best-known example. This is represented as a single period with, say, 0.8 Area under tree and 0.6 Area under crop. The total biomass production of all trees is added together, and that of all crops, and similarly for the parts harvested. If animals graze/browse components of the system, you must estimate what they remove (treat as harvest) or what they bring in as manure (treat as organic additions, Input 8). The problem of acquiring real data is considerable.

Hedgerow intercropping

The basic practice is too well known to require description. The hedgerows are usually pruned several times a year. A purely spatial system is represented as a single Period. The widths of the hedgerows and of the cropped alleys are converted into fractional areas under tree and crop. There is an example on p.34.

In rotational hedgerow intercropping, after a period of intercropping the tree component is allowed to grow, as a form of fallow. After some years it is felled, partly or wholly left on the soil, and intercropping is resumed. With 3 years of intercropping and 5 years of tree fallow, such a system can be represented as:

Period	*Years*	*Area under tree*	*Area under crop*	*Cutyear*
1	3	0.2	0.8	No
2	4	1.0	0.0	No
3	1	1.0	0.0	Yes

Does soil fertility develop differentially beneath hedgerows as compared with alleys? There is a clear *a priori* likelihood of this happening, although there are no reports of it being observed. To study what might be expected to happen, two SCUAF models could be run:

i. Beneath the hedgerows: Prunings placed on the alleys are treated as an 'Other loss' (Input 9).

ii. Within the alleys: Prunings from the hedgerows are treated as an 'Organic addition' (Input 8).

Boundary planting, trees on erosion-control structures, windbreaks and shelterbelts, live fences

In these four practices, the trees are permanent and arranged in linear patterns. Boundary planting and live fences are adopted for purposes not primarily connected with soil improvement, whilst in the other practices, erosion control is the primary purpose. There may be additional beneficial effects upon soil fertility arising from the distribution of tree litter across adjacent land.

A basic assumption of SCUAF, that the effects of trees become more or less evenly distributed over the whole of the area considered, is clearly incorrect if the land use system as a whole is being modelled. You could take a belt of land believed to include tree roots and litter, e.g. 20 m on either side of the line of belt of trees, and estimate soil changes within this belt.

Biomass transfer

Tree leaf litter is harvested from natural forest and carried, manually, onto the cultivated fields. The litter so brought in is represented as an organic addition (Input 8).

Trees on rangeland or pastures, plantation crops with pastures

SCUAF is not designed for, or tested against, sylvopastoral systems. Some of the default values, e.g. for root biomass, are likely to be incorrect, and there is no direct representation of the livestock component. However, both the systems consist of trees above a herbaceous component, in this case grasses and other pasture plants. Users with a knowledge of pastoral and sylvopastoral systems may therefore wish to see whether SCUAF produces reasonable results. All default values should be treated with caution, substituting actual data from grasslands for the crop component where possible. Both systems are represented as a single Period, with, e.g., 0.6 Area under tree and 0.95 Area under crop. The livestock has to be treated as external to the system: plant material eaten by livestock is treated as harvest, and manure production as organic additions (p.67).

Woodlots with multipurpose management, fodder banks

Where woodlots are managed largely or entirely for the purpose of wood production, then these are a form of forestry. If management is multipurpose, particularly if wood production is intentionally not maximized in order to secure other outputs such as forest grazing, then there is an element of agroforestry. Fodder banks are a special type of woodlot in which trees are grown primarily to produce fodder.

These systems can be represented as 1.0, or close to that, Area under tree. The area under crop, whether there is a cutyear, and plant parts harvested will vary with circumstances.

Reclamation forestry leading to multiple use

As an example, consider a system in which an area of degraded land is planted to trees for the purpose of checking further erosion and building up soil fertility. After a number of years, some of the trees are felled, possibly leaving contour-aligned belts, and controlled productive use of the land is started. Taking as an example a reclamation period of 12 years and 60% under crops during the period of production, such a system could be represented as:

Period	*Years*	*Area under tree*	*Area under crop*	*Cutyear*
1	11	1.0	0.0	No
2	1	1.0	0.0	Yes
3	20	0.4	0.6	No

The initial soil conditions (Input 5) are those of the degraded soil. There is no harvest at all in Period 1, and possibly none, or wood only, in the Cutyear. The initial tree growth is entered as fairly slow, using data on what would be expected on degraded soil. Through the feedback effects, growth improves as soil fertility builds up. Questions that could be investigated using SCUAF are: (i) how long will the initial reclamation period need to be in order to restore soil fertility sufficiently for productive use to begin? (ii) is a ratio of 40% trees to 60% crops likely to be sufficient to sustain soil fertility?

Treatment of two agricultural crops per year

There is no design facility in SCUAF to handle double or other multiple cropping, such as takes place in climates with two distinct rainy seasons or with no dry period. Such systems can be entered in two ways.

The first, and recommended, is to add together the biomass of the two (or more) crops as a whole and separately for leaf, fruit and root. The sums are entered as the net primary production of the crop and its parts. If only one of the crops is nitrogen-fixing, enter this as the fraction of the crop component that is nitrogen-fixing.

An alternative is to treat half-years as 'years' in the model, e.g. the outputs under Time = 4 are for the fourth six-month period. For this to be valid, however, the process constants, under Inputs 6 - Erosion and 10 - Soil/plant processes, must be adjusted; the appropriate values for many of them will be about half the default values, but not in every case. This latter procedure is scientifically 'risky', requiring careful consideration of the implications of six-month time units for the functioning of the model.

Comparison with non-agroforestry systems

In evaluating agroforestry systems, it is not enough to show that they are beneficial: they must be shown to be preferable to alternative kinds of land use. Not only existing practices, but possible improved forms of agriculture or forestry can be used in such comparisons. If forest clearance is being considered, the proposed introduction of agroforestry might be compared with that of natural vegetation.

SCUAF does not provide a complete appraisal of an agroforestry or other land-use system. Its primary function in evaluation is to estimate the likely impact upon soil conditions, a major component in sustainable land use. There is a secondary output, in that the model shows the harvest expected year by year, and some of the inputs (e.g. manure, fertilizer) needed to obtain this output.

Natural vegetation

Data from studies of natural ecosystems can be analyzed. For forests and woodlands, enter the canopy trees as the tree component and the understorey as the 'crop'. For savannas, the trees and grasses become the tree and crop components respectively. Ideally, natural ecosystems that are believed to be in a steady state should produce unchanging soil conditions. This was one of the sources used to calibrate SCUAF.

To represent forest clearance, run the natural ecosystem for 10 or more years, then enter a cutyear (with burning and/or harvest), followed by whatever is assumed to be the new use under which the land is placed.

Agriculture

Agricultural monoculture is represented as a single period, with Area under tree 0.0 and crop 1.0.

For systems with (herbaceous) intercropping, e.g. a cereal and a herbaceous legume, an artificial device is available. There is no need for the 'tree component' in SCUAF to be a tree! Enter one crop as the 'tree', with the woody part zero, and the other as the crop. Each crop can be specified as nitrogen-fixing or not. Intercropping can then be represented by the respective areas under the two components. The parts of each crop that are harvested are similarly specified. For rotational intercropping, e.g. two growing seasons with maize and beans respectively, see p.103.

Forestry

Felling of natural forest has been noted under natural vegetation above. Plantation forestry might be represented, e.g. for a cycle of 18 years in the last of which felling takes place, as:

Period	*Years*	*Area under tree*	*Area under*	*Cutyear crop*
1	17	1.0	0.0 *	No
2	1	0.0 **	0.0	Yes

* Or more, using 'crop' to represent the forest understorey.
** Zero if there is no tree growth for all or most of that year.

Replanting, at the start of Period 1, then automatically returns. SCUAF could be used to compare the effects of whole-tree harvesting with return of branches and chipping, or to examine soil trends under seconnd- and third-rotation forestry.

Pastoralism

The same remarks apply as given above for sylvopastoral systems. It is possible to enter grassland as the crop component in SCUAF, but the model has not been calibrated for this and some of the default values will be inappropriate. A comparison between sylvopastoral land and livestock without trees might be possible, making identical assumptions for the grass (crop) component in both cases, then adding the tree component to the sylvopastoral system.

Horticulture

Many systems of fruit trees are in fact forms of agroforestry, often with a grass cover which may be either grazed and mown and harvested. These can be entered as spatial agroforestry systems. The proviso noted above applies, that grassland may require changes to the default values of the crop component.

Other kinds of land use

SCUAF has not been designed, nor tested, for irrigated agriculture, intensive urban use or other kinds of land use. The further removed the land-use system is from trees with agricultural crops, on which SCUAF was based, the more likely is it that the default values and some of the processes will require adjustment.

Handling greater complexity

SCUAF has intentionally been made simple to make it easy to use. The price of this simplicity is that some complexities that occur in real land-use systems cannot be represented. You cannot, for example, enter plant growth at one rate for so many years and then at a faster or slower rate, nor can you specify that a plant part, say tree fruit, is harvested in one period but not in another.

For users who wish to enter data in which values of variables change with time (other than as a result of soil changes), there is a method available. Suppose some variables (e.g. growth rates, additions, removals) should be changed between two time periods, each of three years. This situation can be entered, and outputs obtained, as follows:

1. Enter data for the first period, say with file name STARTMOD.
2. Obtain printed outputs for three years.
3. Change the file name to NEXTMOD.
4. Enter the soil conditions at the end of Year 3 for the first period as the **Initial** soil conditions for the second period.
5. Now modify, as required, all other data for the second period.
6. Obtain outputs for the next three years.

Sets of outputs will now be stored on the data subdirectory in separate files covering three years. For example, changes in erosion will be stored as STARTMOD.ERO and NEXTMOD.ERO respectively. These can be combined, either by hand and by importing one onto the other in a graphics package, to obtain six-year outputs. It is even possible to do this year by year, thus allowing data such as varying rates of tree growth to be entered.

This procedure is slower than normal runs of SCUAF, but may be worth carrying out if year-by-year data are available.

8 TECHNICAL ASPECTS

SCUAF runs on IBM-compatible microcomputers using the MS-DOS/PC-DOS operating system. A minimum of 512 kB RAM memory is required. A hard disk is preferable, but except for the automatic graph-plotting facility it can be run on twin diskette drives.

Tabular output is written to the screen or, by entering CONTROL + P, to the screen plus printer. At the same time, all outputs are stored on disk as files of the form FILENAME.EXT, where FILENAME is the name of a model and EXT is an extension dependent on the type of output. These are ASCII files that can be processed independently by the user, e.g. imported into a graphics package. Outputs, and any models that have been saved, are stored under the following subdirectories (unless otherwise specified under Utilities Menu 3) and extensions:

Subdirectory C:\SCUAF\MODEL

FILENAME.SCU	Input data of model with file name FILENAME

Subdirectory C:\SCUAF\OUTPUT

FILENAME.SYS	Output of:agroforestry system
FILENAME.ERO	erosion
FILENAME.CA1	soil carbon, one-fraction
FILENAME.CA2	soil carbon, two-fraction
FILENAME.TOT	total biomass and carbon
FILENAME.NI1	soil organic nitrogen, one-fraction
FILENAME.NI2	soil organic nitrogen, two-fraction
FILENAME.MIN	soil mineral nitrogen
FILENAME.SYN	plant-soil system nitrogen
FILENAME.GRO	plant growth
FILENAME.HAR	harvest

SCUAF was written in Microsoft Pascal, chosen as the most robust language available at the time, and one that readily allows for the system of default values dependent on conditions of the physical environment. The files UPDATE and USERPLOT were written in Turbo Prolog, which facilitates the 'window' type of screen prompts.

The functions of files forming the SCUAF model Version 2.0 are:

SCUAF20.EXE	The main compiled executive program file
UPDATE.EXE	Keeps a record of all outputs; creates a file MODELS.CXT
USERPLOT.EXE	Connects SCUAF with LOTUS 1-2-3, making use of data stored in MODELS.CXT
AUTO123.WK1	Directs LOTUS to follow the instructions for producing a graph that have been created by USERPLOT.EXE

In the course of running the program, the following file is created on the SCUAF subdirectory:

MODELS.CXT	Keeps a record of all models obtained.

In addition, a file FILENAME.CXT is created in the subdirectory C:\SCUAF\OUTPUT, which contains a record of all outputs obtained from the model FILENAME; this record is used in screen graph prompts.

If there are minor modifications to Version 2.0, these will be issued as Versions 2.1, 2.2, etc.. The corresponding executive program files will be identified as SCUAF21.EXE, SCUAF22.EXE, etc..

The main part of SCUAF.EXE is a module SIMULATE, which calculates all values year by year, starting with the initial values and proceeding iteratively. Whichever output is called for, SIMULATE calculates the entire set of outputs, displaying only the one selected. If the user selects (under Input 1 - Cycle) the carbon cycle only, nitrogen input prompts are suppressed and the nitrogen feedback values are set to zero and cannot be changed.

A difficulty arises with interactive models where it is wished, on the one hand, for the computer to calculate a value automatically, and on the other, for the user to be able to alter this value. This is covered by setting such variables to an artificial default value of minus 1. Where the model finds the current value of the variable is negative, it calculates it from data entered previously. Where it finds the value is positive, i.e. the second time that the input section is entered, it retains this value, which the user may then alter.

Graph plotting

The automatic graph-plotting facility requires that the user should possess the LOTUS 1-2-3 program, which must be placed in a subdirectory C:\LOTUS.

Any graphics files that are saved in LOTUS 1-2-3 for purposes of printing are saved in the form FILENAME.PIC. If more than one output from a given model is saved, it is necessary to contract the file name so as to include the extension indicating the type of output (p.94), e.g.:

The graph of FILENAME.ERO is stored as FILENERO.PIC

or where successive runs of a model, as FILENAM1, FILENAM2, ... are made:

The graph of FILENAM1.ERO is stored as FILE1ERO.PIC

Before using LOTUS 1-2-3 for purposes other than SCUAF, the file AUTO123.WK1 must be erased from the Lotus subdirectory. Do not erase it from the SCUAF subdirectory.

Graph plotting using other programs

If the user does not possess the Lotus 1-2-3 program, but has another graph-plotting program, graphs can still be obtained. All numerical outputs (tables) are stored as ASCII files in the SCUAF/OUTPUT subdirectory. To check this, they can be viewed on the screen by entering DOS and typing TYPE FILENAME.EXT. These files can be imported into other graph-plotting programs.

APPENDICES

1. **The SCUAF input form.**
2. **SCUAF default values.**

THE SCUAF INPUT FORM

1 CYCLE

Cycle selected for modelling:

1 Carbon Cycle
2 Carbon and Nitrogen Cycles

If carbon cycle only is selected, input data on nitrogen is not required.

2 DOCUMENTATION

File name
Title
Source
Country
Location
Date
Notes

3 PHYSICAL ENVIRONMENT

Climate:
1 Lowland humid
2 Lowland subhumid
3 Lowland semi-arid
4 Highland humid
5 Highland subhumid
6 Highland semi-arid

Soil texture:
1 Medium textured
2 Sandy
3 Clayey

Drainage:
1 Free
2 Imperfect
3 Poor

Soil reaction:
1 Strongly acid
2 Acid
3 Neutral
4 Alkaline

Slope class:
1 Flat
2 Gentle
3 Moderate
4 Steep

4 AGROFORESTRY SYSTEM

	Period					
	1	2	3	4	5	6
Length (years)						
Fraction of land under tree						
Fraction of land under crop						
Is it a cutyear? (Yes/No)						
What fraction of tree is N-fixing?						
What fraction of crop is N-fixing?						

5 INITIAL SOIL CONDITIONS

DEPTH

Topsoil depth (cm)
Soil depth considered (cm)
Total depth of soil (cm)

CARBON

Initial Carbon, Topsoil (percent)
Initial Carbon, Subsoil (percent)
Bulk density, Topsoil (g/cc)
Bulk density, Subsoil (g/cc)
Initial soil Carbon (kg/ha)

NITROGEN

Initial Nitrogen, Topsoil (percent)
Initial soil Nitrogen (kg/ha)

6 EROSION

Soil Erosion (kg/ha/yr) = Climate Factor * Soil Erodibility Factor * Slope Factor * Cover Factor * 1000

Enter best estimate for each factor:

Climate factor
Soil erodibility factor
Slope factor
Cover factor under tree
Cover factor under crop

Soil erosion under tree (kg/ha/yr)
Soil erosion under crop (kg/ha/yr)

Tree proportionality factor

Measured soil erosion in Year 1 (kg/ha/yr)

Carbon enrichment factor
Nitrogen enrichment factor

Tree, Net Primary Production, above-ground (kg DM/ha/yr)
Crop, Net Primary Production, above-ground (kg DM/ha/yr)

Roots as a fraction of above-ground NPP, tree
Roots as a fraction of above-ground NPP, crop

NPP in parts of tree (kg/ha/yr):
Leaf
Fruit
Wood
Root

NPP in parts of crop (kg/ha/yr):
Leaf
Fruit
Wood
Root

Fractions of Tree retained as growth annually:
Leaf
Fruit
Wood
Root

Fractions of Crop retained as growth annually:
Leaf
Fruit
Wood
Root

Proportion of tree roots that are coarse roots
Proportion of crop roots that are coarse roots

Is any part of tree or crop retained as growth in cutyear? (Yes/No)
If Yes:

Fractions of Tree retained as growth during cutyear:
Leaf
Fruit
Wood
Root

Fractions of Crop retained as growth during cutyear:
Leaf
Fruit
Wood
Root

Fraction of roots growing below soil depth considered:
Tree roots
Crop roots

CARBON

Carbon Fraction in dry mass, Tree
Carbon Fraction in dry mass, Crop

NITROGEN

Nitrogen % in:	or	Carbon:Nitrogen ratio of:
Tree Leaf		Tree Leaf
Tree Fruit		Tree Fruit
Tree Wood		Tree Wood
Tree Root		Tree Root
Crop Leaf		Crop Leaf
Crop Fruit		Crop Fruit
Crop Wood		Crop Wood
Crop Root		Crop Root

8 ADDITIONS

	Period					
	1	2	3	4	5	6
Organic (kg DM/ha/yr)						

Carbon fraction in organic additions
Nitrogen percent in organic additions
or Carbon:Nitrogen ratio in organic additions

	Period					
	1	2	3	4	5	6
Fertilizer (kg/ha/yr)						

Nitrogen fraction in fertilizer

9 REMOVALS

A: HARVEST

Fraction of Tree harvested annually:
Leaf
Fruit
Wood
Root

Fraction of Crop harvested annually:
Leaf
Fruit
Wood
Root

Additional fraction of Tree harvested in cutyear:
Leaf
Fruit
Wood
Root

Additional fraction of Crop harvested in cutyear:
Leaf
Fruit
Wood
Root

B: OTHER LOSSES FROM SYSTEM

Are there any losses of plant material from the system other than harvest (e.g. burning)? (Yes/No) If Yes:

Fraction of Tree lost annually:
Leaf
Fruit
Wood
Root

Fraction of Crop lost annually:
Leaf
Fruit
Wood
Root

Additional fraction of Tree lost in cutyear:
Leaf
Fruit
Wood
Root

Additional fraction of Crop lost in cutyear:
Leaf
Fruit
Wood
Root

10 SOIL PROCESSES

CONVERSION LOSSES (Litter to Humus)

Fraction of above-ground parts lost through oxidation
Fraction of roots lost through oxidation
Fraction of organic additions lost through oxidation
Fraction of coarse tree roots decaying at least 1 year later
Fraction of coarse crop roots decaying at least 1 year later
Fraction of remaining coarse tree roots decaying 2 years later
Fraction of remaining coarse crop roots decaying 2 years later

HUMUS DECOMPOSITION CONSTANTS

Number of humus fractions considered (1 or 2)

LABILE HUMUS
K for the tree
K for the crop

For 2-fraction humus only:

STABLE HUMUS
K for the tree
K for the crop
Fraction of initial humus in stable form
Fraction of humified litter becoming labile humus
Fraction of labile humus transformed annually to stable

NITROGEN CYCLE

NITROGEN GAINS

Symbiotic Fixation per unit area of N-fixing Tree (kg/ha/yr)
Symbiotic Fixation per unit area of N-fixing Crop (kg/ha/yr)
Fraction of symbiotic fixed N entering soil humus

Non-Symbiotic Fixation (kg/ha/yr)
Throughfall and stemflow (kg/ha/yr)

NITROGEN LOSSES

A. Mineral N of organic origin:

Fraction of mineral N leached under tree
Fraction of mineral N leached under crop

Fraction of mineral N lost
- by gaseous losses (denitrification + volatilization)
- by fixation onto clay minerals (net)

B. Fertilizer N:

Fraction of fertilizer N leached under tree
Fraction of fertilizer N leached under crop

Fraction of fertilizer N lost:
- by gaseous losses (denitrification + volatilization)
- by fixation onto clay minerals (net)

11 SOIL/PLANT FEEDBACK FACTORS

CARBON

Rise or fall in soil carbon, relative to initial state, of 1 percent causes increase or decrease in rate of plant growth by x percent:

For Tree
For Crop

NITROGEN

Rise or fall in soil nitrogen, relative to initial state, of 1 percent causes increase or decrease in rate of plant growth by x percent:

For Tree
For Crop

SOIL DEPTH

Increase or decrease in soil depth, relative to initial state, of 1 percent causes or decreases in rate of plant growth by x percent:

For Tree
For Crop

NOTES

SCUAF DEFAULT VALUES

FILE NAME	FILENAME
TITLE	TITLE

Physical Environment

CLIMATE=	Lowland subhumid
TEXTURE=	Medium textured
DRAINAGE=	Free
REACTION=	Acid
SLOPE=	Gentle

Agroforestry System

PERIOD	YEARS	AREA UNDER TREE	AREA UNDER CROP	CUT-YEAR
1	5	0.4	0.6	No

Soil Conditions

TOPSOIL DEPTH (cm)=	20.00
SOIL DEPTH CONSIDERED (cm)=	20.00
TOTAL SOIL DEPTH (cm)=	200.0
BULK DENSITY, TOPSOIL (g/cc)=	1.3
BULK DENSITY, SUBSOIL (g/cc)=	1.5

	CLIMATE 1	2	3	4	5	6
INITIAL CARBON, TOPSOIL (percent)=	2.00	1.00	0.50	3.00	1.50	0.75
INITIAL CARBON, SUBSOIL (percent)=	0.50	0.25	0.125	0.75	0.375	0.188
INITIAL SOIL CARBON (kg/ha)=	52000	26000	13000	78000	39000	19500

For Sandy Texture, multiply initial carbon and nitrogen by	0.50
For Clayey Texture, multiply initial carbon and nitrogen by	1.25

INITIAL TOPSOIL C:N RATIO:	Normal=	10.0
	Poor Drainage and/or Strongly Acid Reaction=	15.0

CLIMATE

For C:N Ratio 10.0:	1	2	3	4	5	6
INITIAL N, TOPSOIL (percent) =	0.20	0.10	0.05	0.30	0.15	0.075
INITIAL SOIL N (kg/ha) =	5200	2600	1300	7800	3900	1950

Erosion

CLIMATE

	1	2	3	4	5	6
RAINFALL FACTOR =	1000	500	200	800	400	150
TREE COVER FACTOR =	0.006	0.01	0.10	0.006	0.01	0.10
CROP COVER FACTOR =	0.40	0.60	0.80	0.40	0.60	0.80

Soil Texture

	Medium	Sandy	Clayey
SOIL ERODIBILITY FACTOR =	0.30	0.20	0.10

Slope Class

	Flat	Gentle	Moderate	Steep
SLOPE FACTOR =	0.00	0.35	3.50	11.00

TREE PROPORTIONALITY FACTOR =	0.8
SOIL EROSION, YEAR 1 (kg/ha/yr) =	Calculated from above factors
CARBON ENRICHMENT FACTOR, ERODED SEDIMENT =	2.0
NITROGEN ENRICHMENT FACTOR, ERODED SEDIMENT =	2.0

Plant Growth

Climate

	1	2	3	4	5	6
NET PRIMARY PRODUCTION kg DM/ha/yr						
TREE	20000	10000	5000	16000	8000	4000
CROP	12000	9000	6000	12000	9000	6000

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

NPP OF PLANT PARTS

	PART	TREE	CROP
Calculated from NPP, as percent:	Leaf	32%	67%
	Fruit	2%	33%
	Wood	66%	0%
Calculated from Root Fraction above:	Root	(40%)	(40%)

BIOMASS FRACTION RETAINED AS GROWTH ANNUALLY

PART	TREE	CROP
Leaf	0.00	0.00
Fruit	0.00	0.00
Wood	0.90	0.00
Root	0.67	0.00

BIOMASS FRACTION RETAINED AS 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 GROWING BELOW SOIL DEPTH CONSIDERED

PART	TREE	CROP
Root	0.40	0.20

FRACTION OF ROOTS THAT ARE COARSE ROOTS

TREE	CROP
0.40	0.00

CARBON AS FRACTION OF BIOMASS, TREE= 0.5
CARBON AS FRACTION OF BIOMASS, CROP= 0.5

Additions

ORGANIC ADDITIONS, PERIODS 1-6 = (kg/ha/yr) 0.0
CARBON AS FRACTION OF ORGANIC ADDITIONS= 0.5
CARBON:NITROGEN RATIO IN ORGANIC ADDITIONS= 25.0

INORGANIC ADDITIONS:
FERTILIZER PERIODS 1-6 = (kg/ha/yr) 0.0
NITROGEN FRACTION IN FERTILIZER= 0.2

Removals

FRACTION HARVESTED 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 HARVESTED 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

LOSSES OTHER THAN IN HARVEST= Nil for all Plant Parts, annually and in Cutyear

Carbon Cycle

LITTER-TO-HUMUS CONVERSION LOSSES:	Soil Texture		
	Medium	Sandy	Clayey
ABOVE-GROUND PLANT RESIDUES =	0.85	0.90	0.75
ROOTS =	0.67	0.70	0.60
ORGANIC ADDITIONS =	0.67	0.70	0.60

NUMBER OF HUMUS FRACTIONS CONSIDERED = 1

FRACTION OF COARSE ROOTS DECAYING >= 1 YEAR LATER:	TREE	CROP
	1.00	0.00

FRACTION OF REMAINING ROOTS DECAYING 2 YEARS LATER:	TREE	CROP
	0.25	0.00

HUMUS DECOMPOSITION CONSTANTS:

	Climate					
	1	2	3	4	5	6
LABILE HUMUS						
K UNDER TREE =	0.03	0.03	0.03	0.023	0.023	0.023
K UNDER CROP =	0.04	0.04	0.04	0.03	0.03	0.03
K UNDER SYSTEM =	Calculated from proportional areas under Tree and Crop					

For 2-fraction humus only:

STABLE HUMUS:
K UNDER TREE = 0.005
K UNDER CROP = 0.005
K UNDER SYSTEM = Calculated from proportional areas under Tree and Crop

PROPORTION OF INITIAL CARBON IN STABLE FORM = 0.667
FRACTION OF HUMIFIED LITTER BECOMING LABILE HUMUS

PLANT PART	FRACTION
Leaf	1.0
Fruit	1.0
Wood	1.0
Root	1.0

FRACTION OF LABILE HUMUS TRANSFORMED ANNUALLY TO STABLE = 0.01

Nitrogen Cycle

FRACTION OF TREE THAT IS N-FIXING:	See Agroforestry System, above
INITIAL CARBON:NITROGEN RATIO	See Soil Conditions, above
INITIAL TOPSOIL NITROGEN (percent)	
INITIAL SOIL NITROGEN (kg/ha)	
NITROGEN ENRICHMENT FACTOR, ERODED SEDIMENT =	See Erosion, above
FERTILIZER NITROGEN (kg/ha/yr) =	See Additions, above

NITROGEN IN PLANT PARTS (percent):

PART	TREE	CROP
Leaf	2.5	1.0
Fruit	2.5	2.5
Wood	0.5	0.5
Root	1.51	1.51

CARBON:NITROGEN RATIO IN

PART	TREE	CROP
Leaf	20	50
Fruit	20	20
Wood	100	100
Root	33	33

NITROGEN GAINS

SYMBIOTIC FIXATION

- PER UNIT AREA OF N-FIXING TREE (kg/ha/yr) =	100.0
- PER UNIT AREA OF N-FIXING CROP (kg/ha/yr) =	100.0
- PER UNIT AREA OF SYSTEM (kg/ha/yr) =	40.0
FRACTION OF SYMBIOTIC FIXATION ENTERING SOIL HUMUS =	0.1

	Climate					
	1	2	3	4	5	6
NON-SYMBIOTIC FIXATION (kg/ha/yr) =	8.0	4.0	2.0	8.0	4.0	2.0
ATMOSPHERIC INPUTS (RAIN, DUST) (kg/ha/yr) =	12.0	6.0	3.0	12.0	6.0	3.0
THROUGHFALL AND STEMFLOW (kg/ha/yr) =	10.0	5.0	2.5	10.0	5.0	2.5

FRACTION OF NON-SYMBIOTIC FIXATION ENTERING SOIL HUMUS = 0.0

NITROGEN LOSSES

A. MINERAL N OF ORGANIC ORIGIN	Climate					
	1	2	3	4	5	6
FRACTION OF MINERAL N LEACHED UNDER TREE =	0.05	0.03	0.013	0.05	0.03	0.013
FRACTION OF MINERAL N LEACHED UNDER CROP =	0.20	0.10	0.050	0.20	0.10	0.050

FRACTION OF MINERAL N LEACHED UNDER SYSTEM = Calculated from Areas under Tree and Crop

FRACTION OF MINERAL N LOST

- BY GASEOUS LOSSES =	0.05
- BY FIXATION ONTO CLAY MINERALS =	0.00

B. FERTILIZER N:

FRACTION OF FERTILIZER N LEACHED UNDER TREE =	2.0 times mineral N of organic origin
FRACTION OF FERTILIZER N LEACHED UNDER CROP =	
FRACTION OF FERTILIZER N LEACHED UNDER SYSTEM =	

FRACTION OF FERTLIZER N LOST:

- BY GASEOUS LOSSES =	0.10
- BY FIXATION ONTO CLAY MINERALS = 0.00	

SOIL TEXTURE = SANDY: Multiply all leaching values by	2.0
" " = CLAYEY: " "	0.5
DRAINAGE CLASS = IMPERFECT: " "	0.5
" " = POOR: " "	0.1

Effects of Soil Texture and Drainage Class are cumulative

Feedback Factors

	TREE	CROP
CARBON/GROWTH =	0.25	0.50
NITROGEN/GROWTH =	0.25	0.50
DEPTH/GROWTH =	0.50	1.00

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SCUAF is a computer program, Soil Changes Under Agroforestry, which estimates changes in soil properties under specified agroforestry systems within given environmental conditions. The soil properties included in Version 2 are rates of erosion, changes in soil organic matter (represented by carbon), and nitrogen cycling. The effects of soil changes upon plant growth and harvest are also estimated.

The model can be employed to assist in the design of agroforestry systems for field trials; to investigate whether a proposed agroforestry system is likely to be sustainable, from the aspect of soil conservation; to indicate what data are required from experiments, if soil changes are to be forecast; and for exploratory conceptual work and agroforestry training. It can be used to extend results from experimental work, for example, to study the probable effects of changing one or more variables. The effects on soils of other land use systems, in agriculture or forestry, can be compared with those of agroforestry.

The computer program on diskette accompanies, and forms an integral part of, this handbook.

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