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# REST PERIOD REQUIREMENTS OF TROPICAL AND SUBTROPICAL SOILS UNDER ANNUAL CROPS

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SUMMARY

As part of the FAO/UNFPA project to estimate the human carrying capacity of the world's land resources, an enquiry was conducted into the needs of soils, when used to grow annual crops, for rest periods. A rest period is a year either of fallow or other non-cultivation, e.g. a grass ley. The rest period requirement is such that the soil remains in a steady and productive state in the long term, without undergoing severe or progressive degradation.

The enquiry covered Africa, South and Central America and South and South-east Asia. Three levels of inputs were considered: low, intermediate and high.

Data employed was drawn from published sources, personal experience and a questionnaire. Information was classified according to level of inputs, major climatic division, growing period group and soil type. A computerized data bank was established, enabling information from different sources on similar environments to be compared.

The results are given in terms of the cultivation factor, R, being the percentage of years in which the soil is used for annual crops in a cultivation/ non-cultivation cycle. The values of R (Tables 5.1-3) range from 10 to 90. There are considerable differences between R values at the low, intermediate and high input levels, and between soils of different types, the latter being greatest at the low level.

A consequence of the findings is that differences in land productivity as between the low, intermediate and high input levels, already considerable in terms of crop yields in a given year, are multiplied up to 2 or 3 times when the effect of differing rest period requirements is taken into account. Hence the increase in potential land productivity obtainable by raising farming methods to a higher input level is correspondingly multiplied. Some implications for future development in areas of shifting cultivation are noted.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

# CHAPTER 1

# AIM AND ORIGIN

## 1.1 AIM

The aim of this study is to estimate the acceptable relationship between years under cultivation and years under fallow or other non-arable use, for soils of tropical and subtropical regions. This relationship should be such that the soil remains in a steady and productive state, without undergoing severe or progressive degradation. The agricultural systems considered are confined to the cultivation of rain-fed annual crops. Estimates are given for three defined levels of farm inputs: low, intermediate, and high. The areas covered are Africa, South and Central America, and South and South-east Asia.

The main purpose of the study is to form a contribution to the FAO-UNFPA project on the human carrying capacity of the world's land resources. The results may be of interest in other contexts, for example the future development of areas presently under shifting cultivation, and therefore this report has been written as a self-contained document.

## 1.2 ORIGIN

### 1.2.1 The requirement of soils for a rest period

It is widely observed that soils of tropical and subtropical regions cannot be cultivated continuously under annual crops, such as maize, sorghum or cassava, without undergoing degradation. Such degradation is marked by a fall in crop yields, and a decline in structure, nutrient content and other physical, chemical and biological properties of the soil; if not arrested, it may be followed by erosion.

Under traditional farming the occurrence of falling yields led to the use of natural fallow as a means of soil regeneration. There arose the various farming systems based on alternation of one or a few years of cultivation with a longer period of fallow, in which natural vegetation is allowed to colonize the soil; these systems have become known as bush fallowing or shifting cultivation. In the past, shifting cultivation and swamp rice cultivation formed the two most widespread kinds of land use in the tropics. In the context of this level of farming technology, periods not under cultivation are synonymous with fallow.

Under technically more advanced methods of farming, with higher inputs to the soil, means of maintaining soil fertility have been sought other than taking the land out of cultivation. These consist of inputs of organic manures and, especially, of artificial fertilizers. Experience has shown, however, that there are many combinations of soil type and climate under which it is still impossible to grow annual crops every year, without either soil degradation or inputs at an impracticable or uneconomic level. The soil must be put to some other use, which may be productive, for a proportion of the time; possibilities include a grass or grass-legume ley, a green manure crop or a period under perennial crops. Under such higher levels of technology, a non-cultivation or rest period may still be necessary but it will frequently not be natural fallow.

Thus at all levels of farming inputs there may be a requirement for land used for annual crops to be left fallow or taken into some other use for a proportion of time. With low inputs and on ferralsols under a rain-forest climate the ratio may be as low as 1-2 years of cultivation in a 20-year cultivation-fallow cycle, or 5-10 percent of years under cultivation; with high (but still economic) inputs there are certainly many climate-soil combinations on which this value approaches 100 percent.

### 1.2.2 The human carrying capacity project

The FAO, in conjunction with the United Nations Fund for Population Activities (UNFPA) is engaged in a project to estimate the human carrying capacity of the world's land resources. This is an extension of a previous study of potential land use by agro-ecological zones (FAO, 1978). For a full description of the methodology of this project, reference must be made to reports thereon. As background to the present study, it may be noted that it includes the following stages:

- A climatic inventory, covering major climates and lengths of growing period.
- A soil inventory, based on the FAO-Unesco Soil Map of the World (FAO-Unesco, 1974).
- Study of the potential biomass production and yield of crops, according to climate.
- Study of the soil requirements of crops and the further constraints which soils place upon potential production.
- Selection of the most appropriate crop combinations for each climate and soil, and estimates of their potential yield.
- Lowering of yield by other constraints, e.g. pests and diseases.

In the preceding agro-ecological zones study, two levels of inputs were considered, low and high. The human carrying capacity project makes in addition estimates based on a third input level, intermediate.

It is apparent from the above, greatly simplified, outline of procedures that once the potential yield of an annual crop for a given climate-soil environment has been estimated, the long-term productivity of that environment must be further reduced in proportion to the time the land must be rested from annual crops. The lowering of potential production arising from this factor may be of considerable magnitude e.g. to one fifth in a traditional system requiring four years of fallow to every one of cultivation. Under modern systems there may still be some production (e.g. beef, dairy products) from the non-arable portion of the cycle, but owing to the much lower energy conversion efficiency of livestock production this cannot have the same food value as that of carbohydrate-producing annual crops.

The present study was undertaken in order to estimate this further reduction in potential food-producing capacity arising from the needs of soils for periods of non-arable use. Where traditional farming systems are being considered, this need can be referred to as the 'fallow period requirement', and this term was in fact used in the early stages of the investigation. However, the use of a term implying such an elementary method of restoring soil fertility as fallowing aroused surprise or even opposition among some quarters and it is certainly inappropriate at higher levels of farming technology. Rest period does not have such implications and correctly implies that the soil is rested from the exhaustion of continous annual cropping; it is here employed as a working term to refer to fallow or other non-arable use, by no means necessarily unproductive.

The results of the study are expressed in terms of the cultivation factor, being the percentage of years in the arable/non-arable cycle in which an annual crop is produced. The cultivation factor is defined more fully in Section 2.3.3.

### 1.2.3 Areas covered

The study covers three areas of sub-continental extent: Africa, South and Central America, and South and South-east Asia. Results for Africa cover the whole continent, including the warm temperate zones to both north and south; it should be noted, however, that very little information was in fact obtained from the Mediterranean littoral or from Malagasy. Results for America refer to the whole South American continent including the temperate zone, peninsular Central America as far north-west as Guatemala (but excluding Mexico), and the West Indies. Results for Asia refer to a mainland belt extending from Pakistan to Vietnam, together with the island states of the East Indies; Nepal, the Phillipines, Papua New Guinea and the island of New Britain are included, but not Iran, Afghanistan, Tibet, China, Korea, Japan or tropical parts of Australia. A small amount of data from Pacific islands has been incorporated.

For convenience, these three areas of study are referred to throughout this report as 'Africa', 'America' and 'Asia' respectively.

### 1.2.4 Order of study

In conformity with the order adopted for the main project, the first study of the cultivation factor was confined to information obtained from, or relevant to, Africa. This was completed by one consultant (Young) in December 1978 and an interim report produced including provisional results. The second consultant (Wright) then carried out a quasi-independent study of America, taking cognisance of the methods devised for the African study but deliberately putting aside its results. A second interim report, with independent results for America, was produced in February 1979. Meanwhile the first consultant had commenced work on Asia; taking levels of farm inputs into consideration, the results obtained were found to show no systematic or substantial differences from those for Africa, and so the two sets of data were combined to produce combined Africa-Asia estimates of the cultivation factor. Finally the latter were compared with the results for America, where a systematic difference was found to exist; the two sets of results were finally compared and reconciled (Section 4.7).

# CHAPTER 2

## BASIS AND ASSUMPTIONS

### 2.1 THE ENVIRONMENTAL BASIS

#### 2.1.1 Climate

The climatic classes used as a basis for assessing cultivation factors are the same as those employed in the agro-ecological zones project, with the exception that growing periods are more broadly grouped. The following is a brief outline of this classification, for details of which reference should be made to FAO (1978, pp. 31-38).

The first distinction is into major climatic divisions, distinguished on the basis of mean temperature during the growing period (Table 2.1A). Of the 9 classes, 3 are too cold for crop growth leaving 6 to be considered; the cool temperate class occurs only in South America. It should be noted that a high proportion of the study area (excluding the arid zone) lies within the warm tropics (88 percent for Africa). Consequently effort was directed primarily towards obtaining information for this climate, and the data are much more numerous and the results more firmly based than for the other major climatic divisions.

The second climatic basis is that of the growing period as determined by water availability. The growing period is defined as the period in days when precipitation exceeds half the potential evapotranspiration, plus a period required to utilize an assumed 100 mm of water stored within the rooting zone of the soil. The agro-ecological zones project utilized 30-day class widths, e.g. 120-149 days, 150-179 days. This was found to be an impractical degree of refinement for use in the human carrying capacity project, and use is made of four growing period groups (Table 2.1B). That with less than 75 days has no potential for rain-fed crop production. This leaves three groups which correspond approximately to the major vegetation formation-types of rain forest (growing period ≥270 days), savanna (120-269 days) and xeromorphic vegetation (75-119 days). The growing period groups will be referred to for convenience throughout this report as the forest, savanna and semi-arid zones respectively.

#### 2.1.2 Soil

The study is based on the soil nomenclature of the FAO-Unesco Soil Map of the World (FAO-Unesco, 1974). Data was initially collected and analyzed in terms of the 106 soil units employed in the legend, largely of adjective-noun form (e.g. orthic luvisols, symbol Lo). It became apparent that in most cases the imprecise nature of the data did not justify division into the adjectival subgroups. The results presented are, therefore mostly combined into the 26 main soil groups (e.g. luvisols, vertisols).

Use of individual soil units was retained only in those instances where the data gave positive justification for doing so. These cases are:

- Separation of both humic ferralsols and acric ferralsols, individually, from the remainder of the ferralsol class (for the forest zone only).

Table 2.1

CLIMATIC CLASSES USED AS BASIS FOR ASSESSMENT OF THE CULTIVATION FACTOR

A. MAJOR CLIMATIC DIVISIONS

| No. | Descriptive name | 24-hr mean temperature regime over the growing period | Notes |
|---|---|---|---|
| 1 | Warm tropics | >20°C | |
| 2 | Cool tropics | <20°C | |
| 3 | Cold tropics | <6.5/10°C | Excluded |
| 4 | Warm subtropics | >20°C | |
| 5 | Cool subtropics | <20°C | |
| 6 | Cold subtropics | <6.5/10°C | Excluded |
| 7 | Cool subtropics (winter rainfall) | >6.5°C | = 'Mediterranean' |
| 8 | Cold subtropics (winter rainfall) | <6.5°C | Excluded |
| 9 | Cool temperate | | S. America only |

B. GROWING PERIOD GROUPS

| No. | Descriptive name | Growing period, days | Notes |
|---|---|---|---|
| 1 | Forest zone | 270-365 | |
| 2 | Savanna zone | 120-269 | |
| 3 | Semi-arid zone | 75-119 | |
| 4 | Arid zone | 1-74 | Excluded |

- Separation of humic acrisols from the remainder of the acrisol class (for the forest zone only).

- Division of the nitosols into eutric (with humic) and dystric (mainly operative in the savanna zone, since eutric soils are rare or absent from the forest zone and dystric soils from the semi-arid zone).

As with climates, both extent within the study area and amount of data collected is very unequally divided between soil types. For Africa, 3 main soil groups, ferralsols, luvisols and arenosols, cover 58 percent of the potentially cultivable (i.e. non-arid, non-lithosol) area, and 10 groups cover 84 percent. In South America ferralsols are again dominant but acrisols are relatively more extensive than in Africa. South Asia has a varied soil pattern including large areas of luvisols, cambisols (on old alluvium of the Gangetic plain) and vertisols, whilst South-east Asia is dominated by acrisols.

Hence the data obtained, and the results presented, refer mainly to 10 soil groups:

A Acrisols
B Cambisols
F Ferralsols
G Gleysols
J Fluvisols
L Luvisols
N Nitosols
Q Arenosols
R Regosols
V Vertisols

Much less data was obtained for the following 8 groups, which are of relatively small extent within the non-arid portion of the study area:

E Rendzinas
H Phaeozems
K Kastanozems
O Histosols
P Podzols
T Andosols
W Planosols
X Xerosols

The following 8 groups were excluded for one of two reasons:

| | | |
|---|---|---|
| Absent or rare in the study area: | C | Chernozems |
| | D | Podzoluvisols |
| | M | Greyzems |
| Non-arable: | I | Lithosols |
| | S | Solonetz |
| | U | Rankers |
| | Y | Yermosols |
| | Z | Solonchaks |

Table 2.2 SOIL CLASSES USED AS BASIS FOR ASSESSMENT OF THE CULTIVATION FACTOR

A. MAIN SOIL GROUPS

| Code no. | Symbol | Main soil group | Notes |
|---|---|---|---|
| 010 | J | Fluvisols | |
| 020 | G | Gleysols | |
| 030 | R | Regosols | |
| 040 | I | Lithosols | Non-arable |
| 050 | Q | Arenosols | |
| 060 | E | Rendzinas | Not extensive |
| 070 | U | Rankers | Non-arable |
| 080 | T | Andosols | Not extensive |
| 090 | V | Vertisols | |
| 100 | Z | Solonchaks | Non-arable |
| 110 | S | Solonetz | Non-arable |
| 120 | Y | Yermosols | Arid zone |
| 130 | X | Xerosols | Mainly arid zone |
| 140 | K | Kastanozems | Absent or rare |
| 150 | C | Chernozems | Absent or rare |
| 160 | H | Phaeozems | Absent or rare |
| 170 | M | Greyzems | Absent or rare |
| 180 | B | Cambisols | |
| 190 | L | Luvisols | |
| 200 | D | Podzoluvisols | Absent or rare |
| 210 | P | Podzols | Not extensive |
| 220 | W | Planosols | Not extensive |
| 230 | A | Acrisols | |
| 240 | N | Nitosols | |
| 250 | F | Ferralsols | |
| 260 | O | Histosols | Absent or rare |

B. CODING SCHEME FOR SOIL UNITS

| Code no. | Symbol | Soil unit |
|---|---|---|
| 010 | J | Fluvisols (undifferentiated) |
| 011 | Je | Eutric fluvisols |
| 012 | Jc | Calcaric fluvisols |
| 013 | Jd | Dystric fluvisols |
| 014 | Jt | Thionic fluvisols |
| 020 | G | Gleysols (undifferentiated) |
| 021 | Ge | Eutric gleysols |
| 022 | Gc | Calcaric gleysols |
| | | continuing as in FAO-Unesco (1974,pp.12-13) to: |
| 263 | Ox | Gelic histosols |

For the purpose of a computerized data bank the soil units were numbered in the order they are given in the legend (FAO-Unesco, 1974, p. 12-13), each main soil group being allotted a multiple of 10 and the soil units numbered sequentially within a group (Table 2.2).

The Soil Map of the World also shows soil phases and slope and textural classes. The soil phases and textural classes are taken into account in the main project when assessing crop yields, whilst the slope classes are incorporated in the degradation assessment. To avoid double-counting, these limitations have been excluded from assessment of the cultivation factor.

### 2.1.3 Soil degradation status

As a means of referring to whether existing farming practices appeared to be in equilibrium with the soil, the concept of soil degradation status was employed. This is the degree to which the soil remains in a productive and steady state under specified agricultural practices. (The concept was defined for the purpose of this study and has no general recognition with the human carrying capacity project or other FAO studies.) Four soil degradation classes are employed:

| | |
|---|---|
| No degradation (D1): | Soil remains in a productive and steady state. |
| Degrading (D2): | Soil is undergoing physical, chemical or biological degradation, with associated lowering of productive potential. |
| Severely degrading (D3): | Soil is clearly undergoing erosion and/or other severe physical, chemical or biological degradation. |
| Low-level equilibrium (D4): | Soil is in a steady state, but at a low level of productivity as a result of degradation at some past time. |

Although a necessary part of the conceptual framework of the enquiry, information on soil degradation status was the hardest to acquire. Except for agronomic experiments in which soil organic matter or nutrients were repeatedly sampled, it normally rested only on the personal opinions of those familiar with the area.

## 2.2 THE AGRICULTURAL BASIS

### 2.2.1 Assumptions

Certain assumptions or constraints apply to this stage of the enquiry. The two principal assumptions are the exclusion of irrigated agriculture and of perennial tree and shrub crops. Thus the study is concerned with rain-fed cultivation of annual crops, principally cereals and root crops. At the low input level where local practice is normally monoculture (e.g. of maize, sorghum, hill rice, cassava, potatoes) then the requirement for rest periods is based on this practice. Where mixed cropping or crop rotations are usual, and in all cases at higher input levels, these may be the basis for assessing the cultivation factor.

Cassava, although botanically perennial, is usually treated as an annual crop and included in the enquiry. Leguminous food crops may be included in rotations at higher input levels, or at the low level where this is normal practice. Cultivation of bananas, plantains and sugar cane are excluded.

As noted above, the need for lower frequency of cultivation because of slope steepness is excluded. The results therefore refer to gentle slopes (up to $9^{o}$ or 16 percent); if used in other contexts, cultivation factors should be lowered for steeper slopes.

### 2.2.2 Levels of soil inputs

The period during which the soil can be cultivated is affected both by standards of farm management and levels of input to the soil. Very good management standards no doubt occur under traditional farming technology, just as poor management is certainly sometimes found with modern technology. It is, however, impracticable in a study at continental scale to take account of the quality of farm management and so an average standard is assumed.

Three levels of inputs to the soil are recognised: low, intermediate, high. There are no difficulties in defining the low and high levels, corresponding to traditional farming and modern technology respectively. However, a large number of farmers in developing countries have adopted practices well in advance of traditional levels but lack either the technical knowledge or the capital resources to utilize the full range of modern inputs; in particular, they may not have the financial loan or other risk-survival resources to be able to apply very high levels of fertilizers. Such people, often called 'better' or 'improved' farmers, have an important contribution to make to food production both now and in the future and are therefore considered in this study.

In the terms of reference, the intermediate level of inputs was defined as approximating to recommended standard extension packages in developing countries (FAO, 1978, p. 16). For the present purpose, and in particular for a questionnaire enquiry, a semi-quantitative definition was sought. This was most appropriately phrased in terms of quantities of artificial fertilizer used. An application of the order of 50-100 kg per hectare (combined nutrients expressed as elements) is normal at this level. This is equivalent to 2½-5 50 kg 'bags' per hectare (conceived as 1-2 hundredweight bags per acre in imperial units) of a fertilizer with 40 percent by weight of nutrients.

It should be noted that the inputs considered are those which it is practicable to apply on a field scale. The very high inputs sometimes used on 'infield' or 'garden' plots in traditional farming are excluded, as are the impracticably heavy applications of farmyard manure, of 10 ton per hectare and upwards, that have sometimes been included in agronomic experiments.

The levels of soil inputs considered are therefore as follows:

Low inputs (I1): Traditional methods of farming; no use of artificial fertilizers or transported organic manure.

Intermediate inputs (I2): Methods practised by farmers who follow the advice of agricultural extension services but who have limited technical knowledge and/or capital resources; improved agricultural techniques; fertilizers at levels of the order of 50-100 kg per hectare (combined weight of nutrients expressed as elements) and/or practicable amounts of organic manures.

High-inputs (I3): Modern methods with advanced technology and high capital resources; fertilizers at levels of maximum economic return; chemical weed control; adequate soil conservation measures.

The cultivation factor varies widely between different levels of inputs. Any discussion of the cultivation factor for a given climate-soil combination is therefore only meaningful if the levels of soil inputs are specified.

## 2.3 RELATIONS BETWEEN SOIL RESOURCES AND AGRICULTURAL PRACTICES

### 2.3.1 The rest period requirement

As noted above, rest period is used here as a working term to refer to the number of years of fallow or other non-arable use in a cultivation cycle for annual crops. In order to meet the need for sustained and acceptable levels of productivity, and to conserve soil resources, there will be a certain minimum rest period necessary under any given combination of climate, soil and input level.

The rest period requirement is the rest period necessary to maintain the soil in a condition which is:

1. in a steady state in the long term (i.e., free from decline in organic matter and nutrients at the commencement of successive periods of cultivation in a cultivation/non-cultivation cycle);

2. at a reasonable level of productivity (as appropriate to the level of inputs concerned);

3. in a physical condition which is not unduly liable to erosion;

4. able to meet crop water requirements.

The first three conditions are common to all environments. The fourth is applicable in the semi-arid zone, where fallowing may be necessary to store moisture for the next year's crop. These requirements are operative at all levels of inputs.

### 2.3.2 The cultivation factor

The critical value towards which this enquiry is directed is the relative lengths of cultivation and non-cultivation (fallow, ley or other). This is suitably expressed in terms of the cultivation factor, R, originally defined by Joosten (1962) but largely known through the work of Ruthenberg (1971/76).

The cultivation factor, R, is the number of years under cultivation as a percentage of the total cultivation/non-cultivation cycle.

$$R = \frac{C}{C + F \text{ or } L} \times 100$$

where C = years of cultivation
F = years of fallow
L = years of ley or other non-arable use.

Thus 3 years of cultivation followed by 10 years of fallow would given a K value of 3/(3+10) x 100 = 23 percent.

The cultivation factor so defined is preferable to the 'land-use factor' of Allan (1965), defined as (C+F)/C, since the R factor varies more conveniently from 0 under no cultivation at all to 100 under continuous cultivation.

A complication exists in some regions, (notably parts of the Indian sub-continent and equatorial Africa) in the existence of two cropping seasons. In the Indian subcontinent the word 'fallow' may be applied to land rested during one of the two annual cropping seasons. In this study, the cultivation of one crop per year is regarded as continuous cultivation (R = 100), and fallow or other non-arable use is only considered as such where it occurs for at least one year.

In order to convert potential crop production in a single year into average production over a cultivation cycle the percentage values of R should be converted to fractions and used to multiply the single-year production. Thus for a climate-soil-input level combination with a cultivation factor of 33 percent, if the potential crop production in a single year is 2400 kg/ha, the average production over the cultivation/rest period cycle will be 2400 x 0.33 = 800 kg/ha.

## 2.4 CLASSIFICATION AND CODING OF DATA

All information collected on the cultivation factor was related to the environmental data base described above, namely:

3 levels of inputs (I1, I2, I3)
6 major climatic divisions (MCDs nos. 1, 2, 4, 5, 7 and 11) combined with:
3 growing period groups (GPGs nos. 1, 2 and 3)
26 main soil groups subdivided into
106 soil units

Input levels were coded as I1-3, and soil degradation status as D1-4. Years of cultivation (C), fallow (F) and ley or other non-cultivation (L) were abbreviated as, e.g., C2/F10 = two years of cultivation followed by ten of fallow. The cultivation factor R was expressed as a percent.

Thus a record of observed farming practices might be coded as follows:

Environment: 1 - 2 195 Lf

Agriculture: I1 C2/F6 R = 25% D2

This indicates that the observation refers to major climatic division no. 1, the warm tropics; growing period group 2, the savanna zone; and soil unit 195, ferric luvisols. At input level I1, low inputs, a cycle of two years of cultivation followed by six years of fallow is practised, giving a cultivation factor R of 2/8 x 100 = 25 percent. Under this practice the soil is believed to have degradation status 2, i.e. to be declining in productiveness.

A record of an agronomic experiment with high inputs might be coded as follows:

Environment: 1 - 3 090 V

Agriculture: I3 C4/L2 R = 67% D1

The experiment was conducted in the semi-arid zone (3) of the warm tropics (1) on vertisols (V; not known if pellic or chromic). At the high input level (I3) under four years of cultivation followed by a two-year ley the soil remains in a productive and steady state (D1).

It may be noted that information otherwise relevant to the cultivation factor is of little or no use unless the above minimum of environmental and agricultural information is given. It is usually possible from the location to decide on the climate, but many items of otherwise promising information could not be used because the soil was inadequately described.

# CHAPTER 3

## FUNCTIONS OF THE REST PERIOD

### 3.1 THE NEED FOR A REST PERIOD IN SOILS UNDER ANNUAL CROPPING

The benefits accruing from rest periods between intervals of annual crop production were early discovered by practical farmers. It is common to think of soil rest periods in terms of the systems of tropical agricultural collectively known as shifting cultivation, but their need is by no means confined to such systems nor indeed to the tropics. The field systems which remain from Neolithic times were most probably cultivated only intermittently. The three-field system of mediaeval Britain and parts of Europe can be regarded as a natural fallowing system (with a cultivation factor of R = 67). Fallowing as a farming technique was still firmly established in parts of Britain in the 1850s and occasionally used in France in the 1930s (Sigaut, 1975). As part of the agricultural revolution an offensive against fallow was launched in Britain by Arthur Young, and one of the leading agricultural questions from 1800 to 1820 was the controversy between 'fallowists' and 'anti-fallowists'. Fallowing has long been used as a means of moisture conservation in dry farming by modern techniques in North America and Australia.

In the tropics, systems which employ natural fallows have persisted more widely to the present, in part because of the greater need of soils under warmer climates and in part because of the generally less advanced state of technology. The characteristics of shifting cultivation systems have been described many times and need not be repeated here (cf. e.g. Kellogg, 1963; Newton, 1960; Gourou, 1953/66; FAO, 1974). There are differences in practice between the rain forest and savanna zones, as well as many local variations in detail, one of which is the relative lengths of the cultivation and fallow periods.

Under more modern farming, the soil rest period is no longer equated with a natural fallow. It is more likely to be a planted grass or grass-legume ley and thus **contributes** productively to the farming system. This improved practice has long been a standard component in farming systems of temperate lands; in Britain, for example, it is normal under cereals or roots to put the land down to a grass ley of some three years, the need varying with the intrinsic properties of the soil. In the tropics, the success of grass-legume leys in improving soil conditions as well as,or better than,natural vegetation has been demonstrated many times on experiment stations (Thomas, 1973), although adoption of the practice by farmers is infrequent.

Much of the research in the tropics into rest periods was conducted in the 1950s and 1960s, under pressure of the need to find alternatives to shifting cultivation. It was successfully demonstrated first, that the lengths of rest periods could be considerably reduced by applications of fertilizer and/or organic manures; and secondly, that productive leys were an alternative to bush fallow. Results with the use of green manure crops were varied. It may be supposed, however, that the philosophy behind much of this experimentation was that by continued advances in techniques, the need for soil rest periods could be progressively reduced and eventually eliminated. Only recently, with the rise in fertilizer costs and greater realization of the social and economic problems facing farmers in the tropics, has it become appreciated that farming based on a balanced alternation between periods of cultivation and non-cultivation may be the only realistic way of maintaining many soil units in a productive and steady state.

## 3.2 FUNCTIONS OF THE REST PERIOD

Most farmers probably adopt a fallow or other rest period for a single reason which incorporates all others, namely that crop yields have fallen to levels at which they no longer justify the labour expended. On analysing the causes for such decline in yields, at least six distinct reasons may contribute:

(i) To restore plant nutrient status. During annual cropping, nutrients are lost from the soil profile by leaching, root uptake into the crop and subsequent removal at harvest. In acid soils there is a tendency for fixation of nutrients in unavailable forms to increase. The rest period allows for the restoration of nutrients originating from two sources, the atmosphere and rock minerals. Rainfall contains substantial quantities of all major nutrients, whilst in addition nitrogen is extracted from the atmosphere by nitrogen-fixing soil micro-organisms. The weathering of minerals in the lower part of the regolith feeds a supply of nutrients into the soil, and this is partly brought up to the surface by deep-rooting plants. Part of the nitrogen leached downwards through the profile may also be returned through the medium of roots. Weathering rock minerals also provide a source of trace elements which become selectively removed from the soil during cropping.

(ii) To improve organic matter status and soil structure. In many tropical soils the organic matter content of the A horizon falls to about half its natural level after a few years of cultivation, and there is also some fall at deeper levels. Accompanying this is a deterioration in grade of soil structure leading to poorer rooting conditions. There is a corresponding fall in the activity of soil micro-organisms. Both natural fallow and planted leys build up soil organic matter; grass roots are particularly effective in restoring soil structure. The population of soil micro-organisms is progressively built up under a fallow (Maldague, 1960). The cycle of soil carbon under alternating periods of cultivation and fallow, both for systems in which the soil is in long-term equilibrium and for those in which the rest period requirement has been exceeded, has been set out by Nye and Greenland (1960, see esp. Fig. 7, p. 105).

(iii) Control of weeds. This is one of the reasons most frequently given by farmers at the low input level for abandoning their plots. On soils of low fertility, e.g. acrisols, they may not be referring to the sheer volume of weeds as much as to the appearance of certain indicator weeds that tell them of the futility of resowing their crops. On soils of moderate to high fertility it is common to find that invasion by grasses and perennial weeds progressively exceeds the farmer's capacity to control them by hoe or machete and he abandons the plot in favour of a new site.

At the intermediate input level farmers can usually control most weeds by cultivation methods, and at the high input level by cultivation in conjunction with chemical methods of control. There may, however, be certain persistent weeds that defy control by such methods, e.g. deep-rooted species or those which are biologically so similar to the crop as to make chemical control difficult. Weed control is one of the main reasons for persistence of a limited rest period requirement under higher input levels.

(iv) *Control of pests and diseases.* In most soils, monoculture encourages the build-up of pests and diseases associated with a particular crop. At the low input level, fallowing is the only means available to control these, although owing to other reasons for fallowing, cultivation will usually not have persisted long enough for the problem to become serious.

At higher input levels, the application of chemical compounds can usually control the problem at reasonable cost in temperate and cool subtropical regions, but in the warm subtropics and tropics it may become so expensive that a rest period is a preferable alternative. The need for control of pests and diseases is more associated with climate than soil, being favoured by high temperatures and humidities. There may be certain soil units that offer the best living niches for soil-dwelling insect pests, such as the fissures of vertisols or the granular structures of rendzinas.

(v) *Erosion control.* Few farmers at the low input level would specifically advance erosion control as the reason for abandoning a plot. However, in areas where population increase has forced the shortening of fallow periods and the cultivation of steep slopes that would formerly have been left untouched, the onset of erosion shows that fallowing fulfilled this function. With low inputs, fallowing is the only means of erosion control, other than the fact that simple 'dibble-stick' methods of planting disturb the soil less than full cultivation. At higher input levels, physical controls (bunds, terracing, etc.) become possible. Simple grassed bunds are relatively cheap, but the high expense of more complex works may be such that control by, or in conjunction with, a grass ley becomes preferable.

(vi) *Augmentation of soil moisture.* Many of the more fertile soils of the semi-arid zone cannot be sown to annual crops every year. A fallow of one or sometimes two years is needed to build up the store of moisture in the subsoil, which will then be utilized by one seasonal crop. This is one of the standard 'dry-farming' practices, and in the absence of irrigation the need for it is not entirely removed at higher input levels. It is practised on vertisols and some luvisols, cambisols and xerosols. Whilst particularly characteristic of the winter rainfall (Mediterranean) zone, the considerable increases in crop yield that it may bring about have been demonstrated also in the semi-arid summer rainfall environment (Whiteman, 1975).

# CHAPTER 4

# METHODS OF INVESTIGATION

## 4.1 INTRODUCTION

There have been very few attempts to estimate the rest period requirement of soils, and hence the acceptable cultivation factor. Allan (1965) devised a method applicable to farming at the low input level in Zambia, but this was based on conditions in which there was no land shortage and each family took as much land, and utilized as long a fallow period, as it required. Allan's method commences with observations of a society in which there is land to spare and permits calculation of when it will reach the 'critical population density', that is, the maximum that can be supported by existing practices; the tacit assumption is that the cultivation/fallow ratio currently practised is an acceptable one.

Nye and Greenland (1960) made comprehensive studies of the cycling of organic matter and nutrients under shifting cultivation, both in the forest and savanna zones. They provided quantitative estimates of the rates of soil depletion during cultivation and restoration during fallow; these have since been partially supplemented (e.g. Bernhard-Reversat, 1977) but by no means superseded. The results are in terms of climatic-vegetation zones and not specific soil units.

Ruthenberg (1971/76) gave detailed descriptions of tropical farming systems, classified into shifting cultivation ($R<30$), semi-permanent cultivation (R 30-70) and permanent cultivation ($R>70$). His descriptions are comprehensive in almost all respects other than that of the identification of soil unit and estimation of soil degradation status; he makes the general observation that soil resources are usually conserved under both shifting and permanent cultivation but tend to be degraded during what he regards as the transitional stage of semi-permanent cultivation.

Neither these nor other published works provide direct information on the central topic of this enquiry, the rest period requirements for specific climates and soil types. On the one hand, most pedological works, particularly soil survey reports, contain little information on agricultural practices; whilst on the other, descriptions of farming systems rarely contain enough detail to enable the soil unit to be identified. It is for the latter reason that no use could be made of the remarkably detailed records of cultivation/fallow ratios in Uganda by Tothill et al. (1938) or the mapping of land-use systems in Zambia by Schultz (1976). As one further illustration of the difficulty of obtaining specific information on rest period requirements it may be noted that the recent report <u>Shifting cultivation and soil conservation in Africa</u> (FAO, 1974) contains only two pieces of data sufficiently specific to be codified.

Thus the usual approach to an enquiry of this nature, that of synthesis based on a review of published works, was not in itself sufficient. It was therefore combined with two other approaches, those of personal experience (of the consultants themselves and by interview) and a postal questionnaire. These three approaches, through publications, personal experience and questionnaire, will be referred to as <u>sources of information</u> (Section 4.2). The sources cut across data derived from different kinds of observation, which will be called types of information (Section 4.3). Information from different sources and of different types was combined in the data analysis (Section 4.4).

## 4.2 SOURCES OF INFORMATION

### 4.2.1 Publications

For the Africa study a thorough literature search was carried out, using the following sources:

- Index search in Commonwealth Agricultural Bureaux Soils and Fertilizers abstracts;
- Index search in US National Agricultural Library Bibliography of Agriculture;
- Commonwealth Bureau of Soils bibliographies nos. 1130 (Effect of leys, fallows and shifting cultivation on the fertility of tropical and subtropical soils) and 1399 (Effects on soil conditions of the clearing and agricultural development of tropical forest areas);
- DIALOG computerized data search, using keywords 'fallow', 'shifting cultivation', 'continuous cropping/cultivation', 'nutrient cycling' in combination with 'tropical', 'Africa', 'Asia' and main countries.

Over 100 publications containing information in some way relevant to rest periods for soils of Africa were located, although only 62 of these contained data sufficiently specific to allow abstraction into a computerized data bank. Publications in French were included, although it is likely that the search for these was less inclusive than for English-language material.

This material proved to be of value mainly with respect to the medium- and long-term crop trials carried out on a number of agricultural research stations in Africa, together with nutrient cycling studies, few in number but of high quality. Published records of observed agricultural practices were, however, disappointing owing to weak identification of soil unit and lack of estimates of the degradation status of the soil.

For the America study, a similar independent attempt was made to search for relevant published information, using materials available in the FAO Library and archives in Rome. Hispanic-language as well as English sources were included. This search proved disappointing. Much information relevant to rest periods dates from 15-20 years ago when the soils involved could not be adequately classified; in more recent work the soils are identified clearly but very little is said about rest period requirements.

In the light of these experiences by each consultant, and also because of a time constraint, the literature search for the Asia study was less intense, to allow attention to be concentrated on other approaches which had by then been found to be more fruitful. Some published information for Asia is included, but it is likely that a more intensive search would reveal further relevant records of agronomic experimental work.

4.2.2 Personal experience

The consultant for America (Wright) has considerable personal experience, both as a field pedologist with 18 years' work in South and Central America and as a practical farmer. This was supplemented by interviews with FAO experts with experience of this region. In these circumstances it was possible to combine confident identification of soil units with records or recollection of farming practices. This was the main source of information used for the study of South and Central America.

4.2.3 Questionnaire

Notwithstanding the imprecise nature of estimates of the rest period requirement, it was believed that there were many people with local knowledge who would be capable of making estimates relevant to some of the soils of their area. A questionnaire was therefore devised which sought to draw upon this knowledge. The questionnaire for Africa was directed primarily towards information concerning the low level of inputs, with only one question covering the two other levels. In the light of responses to this, the form of the questionnaire was revised for Asia and America, giving the same questions for each of the three input levels and asking for replies for whichever levels there was information. The two questionnaires are given in Appendix A.

Previous FAO experience with questionnaires having at times proved disappointing, the following measures were taken in an attempt to improve the response:

1. The questionnaire was kept short. A reply was requested for any two, or at most three, soil units.

2. French and Spanish translations were used as appropriate.

3. The enquiry was conducted at the technical scientific level, from one research worker to another; it was addressed wherever possible to individuals, sometimes known personally by the consultants, and only where this could not be done to 'The Director', 'The Professor of...' etc..

4. It was repeatedly stressed, in the questionnaire, preamble and covering letter, that any information based on local experience, however imprecise or uncertainly-based the respondent might consider it to be, was better than none at all.

5. An addressed envelope was enclosed for reply.

For Africa and Asia, questionnaires were sent to the following:

- Agricultural research stations;
- University Departments of Soil Science, Agriculture and Geography;
- Some national Soil Survey organizations;
- FAO field staff currently working in, or with past experience of, the study area.

Over 200 questionnaires were distributed. The replies received by the time of compilation of this Report are shown in Table 4.1; some were still being received too late for inclusion and will be incorporated in a subsequent record to be published in a scientific journal.

Table 4.1 QUESTIONNAIRE REPLIES RECEIVED

| Africa | | Asia | | Total | |
|---|---|---|---|---|---|
| Respondents | Soil sites | Respondents | Soil sites | Respondents | Soil sites |
| 26 | 66 | 23 | 49 | 49 | 115 |

A further 10 replies were received regretting inability to answer to questions put.

For the America study, the questionnaire was distributed mainly to FAO field staff. Replies had unfortunately not been received in time for inclusion in this Report. In most respects, however, the personal and shared experience available for South and Central America (Section 4.2.2) was equivalent to the questionnaire data received for other areas.

We are by no means disappointed in the proportion of replies received. Some will not have been delivered, some will have reached institutions where there was no-one present at the time with appropriate knowledge; whilst in other cases the best qualified person will have felt in all honesty unable to reply, since the topic of rest period requirements has rarely been the subject of scientific investigation. A few wrote back to say that this last was the case. One soils institute of long standing in Africa asked for financial support for travel to obtain the answers, and when informed that this was not available, regretted that they possessed no relevant data.

In a questionnaire of this nature, however, it is not the proportion of responses that matters but their absolute number. This contrasts with 'opinion' or 'consumer' type questionnaires in which low response rates are likely to be associated with bias. It will be seen from Table 4.1 that we received information on 115 sites in Africa and Asia, independently assessed by 49 respondents. With only few exceptions we believe these to be carefully considered and reliable estimates.

Locations of questionnaire responses and published sources are shown in Figs. 4.1-2.

## 4.3 TYPES OF INFORMATION

### 4.3.1 Observed agricultural practices

In order to obtain an estimate for the rest period requirement from observa-

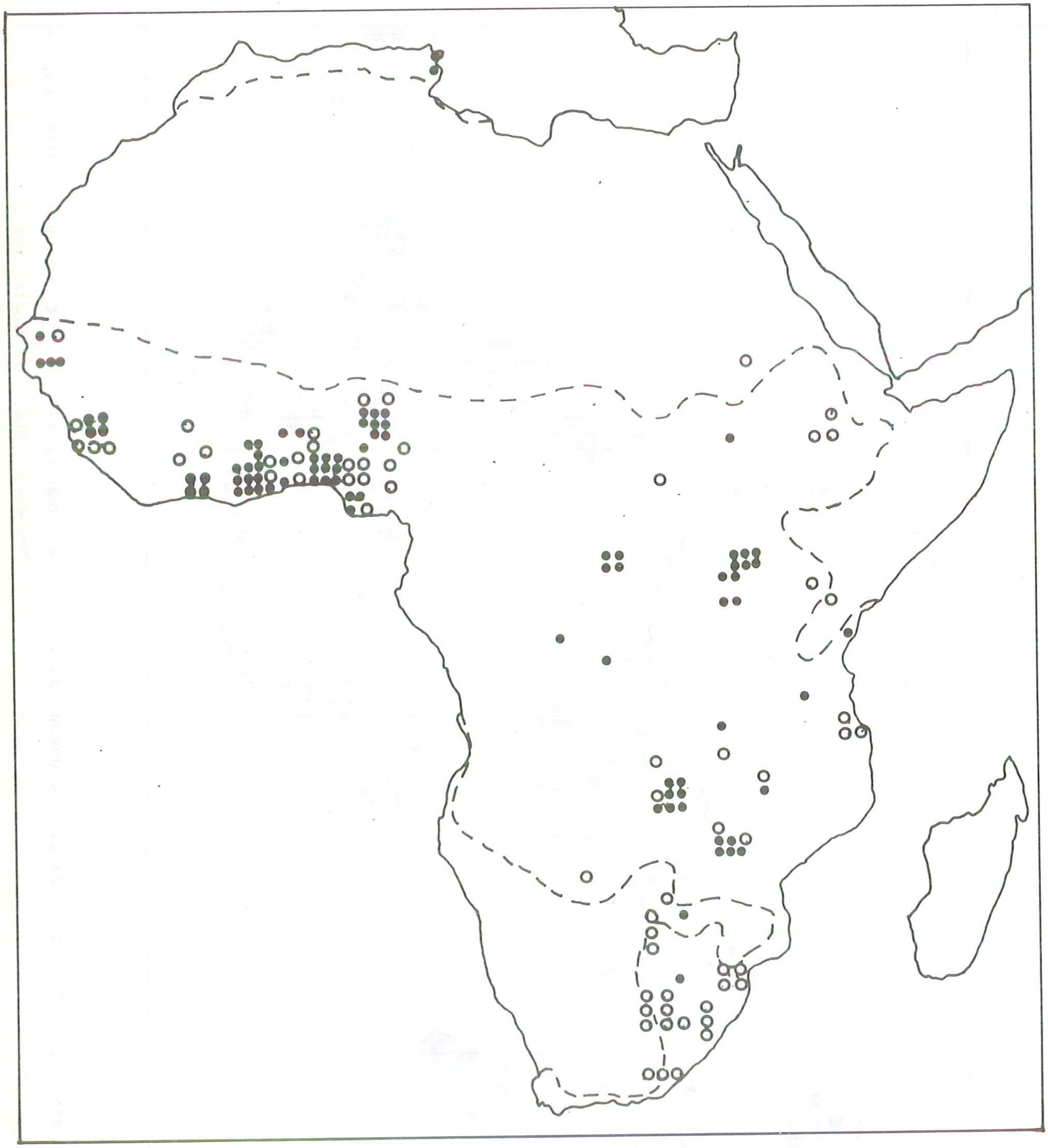

Fig. 4.1: Locations of data sources, Africa.
—‿—‿— : limit of arid zone.
● : publication
○ : questionnaire response.

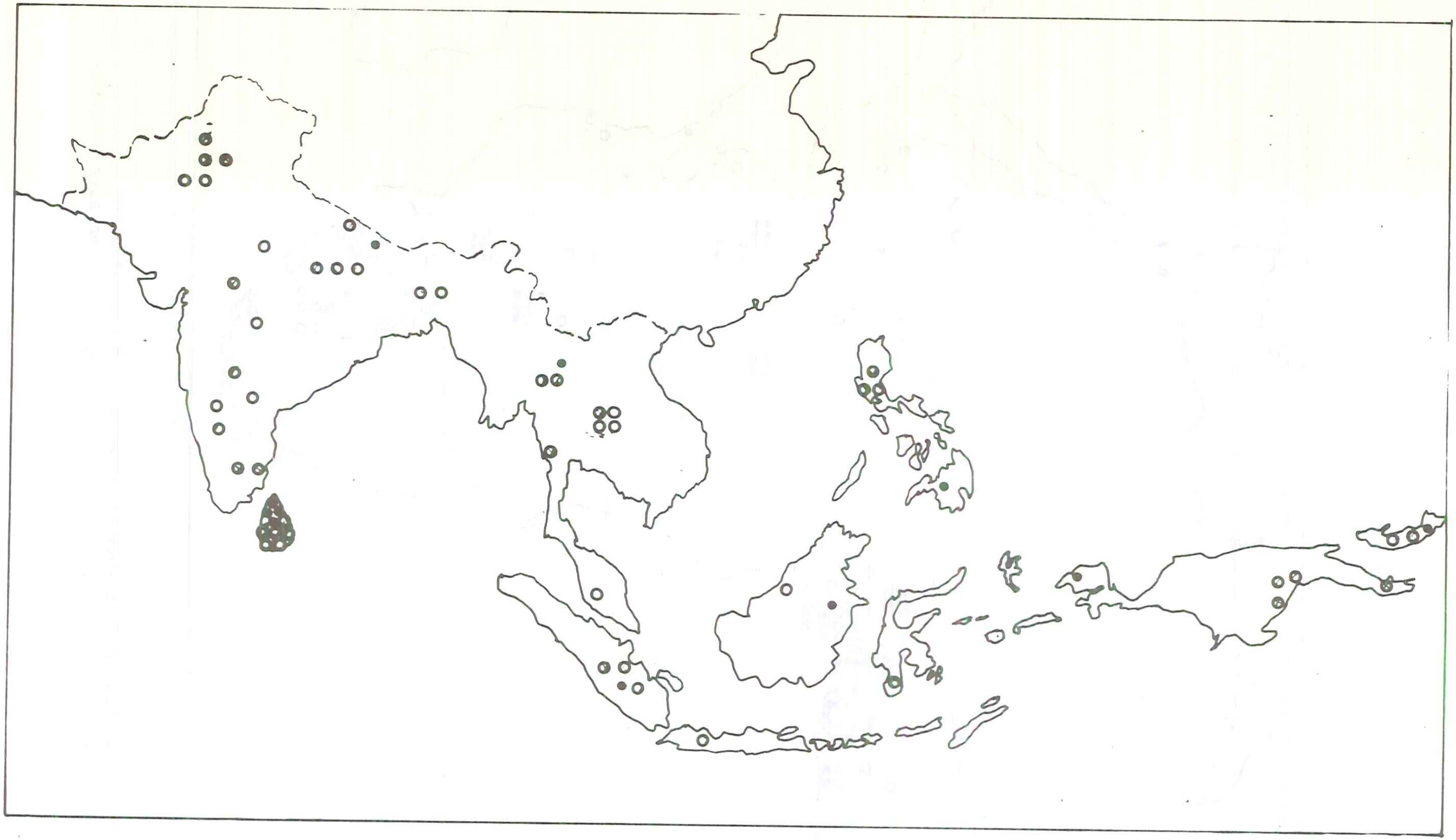

Fig. 4.2: Locations of data sources, Asia. ● : publication, O : questionnaire response.
━━ : limit of study area.

tions of actual agricultural practices, three things must be known or estimated: the climate and soil type, the average number of years of cultivation and non-cultivation, and whether the soil under this rotation appears to be undergoing degradation. If under the observed practices the soil appears to be in a steady state, then it may be said that the maximum acceptable cultivation factor is greater than or equal to the observed factor. For example, if 2 years of cultivation followed by 6 years of fallow (or other non-cultivation) does not appear to be causing degradation, the maximum cultivation ratio is ≥25 percent. If, on the other hand, it appears that soil degradation has occurred or is occurring, as evidenced for example by very low yields or sheet erosion, then the acceptable cultivation ratio is less than that which is observed.

Given the essential prerequisite of soil identification, most published accounts and questionnaire enquiries yielded some estimate of the observed cultivation factor, often as a range, e.g. '2-3 years cultivation followed by 8-15 years fallow'. For long-standing traditional systems of shifting cultivation, with no reports of degradation, it can be assumed that the system is below or close to the critical value. For cases where erosion or other severe degradation is described in the report, it can equally confidently be assumed that the critical ratio has been exceeded. What gave difficulty, however, was to estimate whether the soil was in a steady state for situations in which the cultivation factor had in recent years been increased above former levels, yields were low, but no severe erosion was apparent.

This type of information was obtained from all sources: publications, personal experience and questionnaire response. Its main value was in providing conservative estimates of the cultivation factor at the low input level, through observations of traditional systems still in equilibrium with the environment.

### 4.3.2 Observed soil changes

From publications there are records available of changes to soil organic matter and nutrients following upon specified periods of cultivation, fallow or ley. These were assembled and codified in the hope of building up averages specific to each climate and soil group. It was hoped that, without entering into the full complexities of the nutrient cycle, simple balances between gains and losses of elements per year of cultivation and non-cultivation might be established, if not for every soil then at least for climatic divisions. A stable system at the low input level could then be calculated by ensuring a sufficient rest period to restore losses of all elements.

Despite collection of a substantial amount of data, this aim could not be realised. Recorded gains and losses varied too widely for meaningful averages to be taken. Part of the variability will be due to differences in methods of analysis and depths of sampling; part to the many variables operating other than climatic division and soil group. The only reasonably numerous and consistent values obtained relate to carbon losses, considered in the following section.

### 4.3.3 Studies of nutrient cycling

Certain major studies and compilations of the cycling of carbon and nutrients have been of value in setting limits to the cultivation factor at the low input level for climatic zones. Chief among these are the work of Nye and Greenland (1960), used principally with respect to data on the carbon cycle; and the reviews by Bartholemew (1977) and Greenland (in press) of the nitrogen cycle. One further very detailed review of nutrient cycling based on a symposium (Frissel, 1977) proved to be of limited value, since most of the agro-ecosystems for which data are given are either in temperate latitudes or involve livestock.

Although strictly of the nature of results rather than methods, it is convenient to outline the information used on the carbon and nitrogen cycles prior to the main statement of results. This summary is given in Section 4.4.

### 4.3.4 Agricultural experiments

Many agricultural research stations have conducted medium-term experiments, typically 3-7 years, involving continuous cultivation or cultivation/non-cultivation rotations. In a very few cases the more valuable exercise of a run of the order of 20 years has been achieved. Noteworthy among the latter are work at Sefa, Casamance, Senegal (Charreau and Fauck, 1970), in Rhodesia (Saunder and Grant, 1962; Grant, 1967), at Kwadaso-Kumasi in Ghana (Ofori, 1973), and at two stations in Nigeria, Moor Park Plantation, Ibadan (Vine, 1953), Ahmadu Bello University, Samaru (Jones, 1971) and Yangami, Zaire (Bartholemew et al., 1953).

However, very few such experiments were designed to answer the question, 'What is the acceptable cultivation/fallow ratio at the low level of inputs?'; an exception, directed specifically at this point, is an early study in Sri Lanka (Joachim and Kandiah, 1948). The vast majority of agronomic trials are concerned with fertilizer response, crop variety trials or erosion plots. Those more nearly relevant to the present enquiry are generally directed at one of three questions:

- Is continuous cultivation possible, given inputs to the soil?
- Is a ley, or other productive use, an alternative to fallow?
- More generally, what alternatives are there to shifting cultivation?

It is right and proper that these should be the questions investigated. They came to the fore particularly in the 1960s, when alternatives to shifting cultivation were becoming urgent owing to pressure on land. By no means all such experiments included the monitoring of soil properties; often they describe only whether crop yields could be maintained. It is also common to find the soil nutrient levels at the end of the experiment sampled but regrettably no-one had thought to do this when it started. Rather too many of the continuous cultivation trials last for only 3-5 years, an insufficient period to be confident that steady-state conditions have been established. This type of information has the advantages that levels of inputs are precisely described. Some, however, involve high levels of farm-yard manure (e.g. 12 or even 25 t/ha) such as would be impracticable on a field scale.

Despite being designed for somewhat different purposes, data from such experiments can usefully be brought to bear on rest period requirements. Where it appears that there is no decline in crop yields, or degradation of soil properties, after some years of continuous cultivation or other specified rotation (e.g. Juo and Lal, 1977), it can be tentatively concluded that at the level of inputs given, such a regime is acceptable. Conversely there have been instances where continuous cultivation is very clearly not successful (e.g. Vieweg and Wilms, 1974; North Carolina State University, 1975, p. 121).

This type of information, obtained mostly from published records but in some cases from questionnaire sources, was the main evidence for cultivation factors at the high input level.

4.3.5 Recommended agricultural practices

If government agricultural advisory services incorporated specified cultivation and non-cultivation periods into their recommendations, which could be presumed to be based on substantial local experience, this would have proved a valuable guideline. Both questionnaire and other enquiries showed that only rarely is such matter included in local extension advice. Where included it is not usually specific to different soil units, and in one case known personally to us, current practice bears no relation to the published recommendation. This potential type of information therefore proved to be of very little use, other than in cases where continuous cultivation was recommended at the high level of inputs.

4.3.6 Intrinsic properties of climate and soil

On a priori grounds, relating to relative intensities of oxidation of organic matter, leaching of nutrients and other soil processes, certain climates and soils are likely to have longer rest period requirements than others. These relativities were used for interpolation and extrapolation in cases where no direct evidence on a particular climate-soil combination was available.

With respect to major climatic divisions the following relative positions have been assumed, on the grounds that higher temperatures tend towards a greater risk of soil degradation in general and more rapid oxidation of organic matter in particular:

Warm tropics has higher rest period requirements than cool tropics

Warm tropics has higher rest period requirements than warm subtropics

Warm subtropics has higher rest period requirements than cool subtropics.

With respect to growing period groups, no definite relativities can be stated. Intensity of leaching increases from semi-arid through savanna to rain-forest zones, but so does rate of plant growth during fallows. The classic analysis of shifting cultivation by Nye and Greenland (1960) demonstrated that fallowing was more efficient, in terms of years needed to restore cultivation losses, in the rain forest than in the savanna zone. Set against this is considerable evidence that continuous cultivation of annual crops is less easily achieved in the former than in the latter. Thus no definite a priori difference between the two main arable zones of the lowland tropics, rain forest and savanna, can be established.

Main soil groups can be arranged in the following relative order, commencing with those likely to have highest rest period requirements:

| | Reasons for relative position |
|---|---|
| Arenosols Regosols | Low clay content therefore low organic matter content, high susceptibility to leaching; low water capacity in semi-arid zone. |
| Ferralsols Acrisols | Strong acidity, low base saturation. |
| Luvisols Cambisols | Most intrinsic properties more favourable than soil groups above. |
| Nitosols Vertisols | Mineral input from basic rocks, or less strong leaching; weakly acid to alkaline (except dystric nitosols); high clay content. |
| Fluvisols Gleysols | On level ground and/or in receiving sites. |

To assist comparison of cultivation factors the soil groups are listed in this order in the tables of results.

With respect to soil units it is probable that humic units will have lower rest period requirements than other units in the same main group, and plinthic units higher requirements. Dystric units may be expected to have higher rest period requirements than corresponding eutric units.

Only limited use was in fact made of soil relativities, since direct evidence being preferred wherever available. Considerable use was made of climatic relativities in assigning values to the cool tropics and subtropics, since more evidence was available for the warm tropics than for all other major climatic divisions together.

## 4.4 LIMITS SET BY THE CARBON AND NITROGEN CYCLES

As noted above, an initial aim of building up models for the cycling of organic matter and the major nutrients under each climate and soil unit had to be abandoned owing to the high degree of scatter among the values obtained. In this respect it was reassuring to a similar conclusion at the end of a recent review of nitrogen cycling: "Much further information needs to be collected before any realistic balance sheets can be written for the movement of nitrogen in agricultural ecosystems in the tropics " (Greenland, in press).

Two sets of data could, however, be used to set limits to the cultivation factors at which a steady state might be expected to be obtainable. These are for the carbon and nitrogen cycles. In both cases the data refer to climatic zones as a whole, namely rain forest and savanna, but have been attributed to the most widespread soils in these zones, ferralsols/acrisols and ferric luvisols respectively.

### 4.4.1 The carbon cycle

The basic model for the soil-vegetation carbon cycle is that of Nye and Greenland (1960; cf. Young, 1976, pp. 109-115). This is based on the findings first, that of the carbon present in plant litter and roots, a substantial proportion is rapidly lost by oxidation in the course of its conversion to soil humus; and secondly, that once in the form of humus, the annual rate of further oxidation is a fixed fraction of the humus initially present, this fraction being termed the decomposition constant. Thus:

$$A = f_l L + f_r R$$

and $$B = k_f C$$

therefore $$I = A - B = (f_l L + f_r R) - k_f C$$

where
$A$ = annual addition of humus carbon to the soil
$B$ = annual loss of humus carbon from the soil
$I$ = net increase of soil carbon during a fallow
$L$ = litter fall
$R$ = root death
$f_l$ = fraction of litter becoming humus carbon
$f_r$ = fraction of roots becoming humus carbon
$k_f$ = decomposition constant under fallow
$C$ = humus carbon present in the soil

Since the rate of oxidation of soil carbon is dependent on the amount present, the loss, B, will become slower as the carbon content falls. It can be demonstrated that a steady state will become established such that

$$I = A - pA = 1(1 - p)$$

where $p$ = proportion of the carbon content under natural vegetation.

Nye and Greenland give representative values for the constants involved, for the rain forest and savanna environments. Subsequent studies have confirmed these orders of magnitude. Studies of the decomposition of carbon-14 labelled plant material have confirmed the concept of two stages of oxidation loss: very rapid initial loss, such that some 80 percent of litter may be lost in the first year, followed by a very much slower subsequent decomposition rate (Jenkinson and Ayanaba, 1977; Sauerbeck and Gonzalez, 1977).

Taking representative values for the two climatic-vegetation zones, the soil carbon balance at two levels of equilibrium is shown in Table 4.2. It is reasonable to assume that at the low input level, acceptable values of the cultivation factor lie somewhere between the lower value at the 75 percent equilibrium level and the upper limit at the 50 percent level, taking the values for savanna burnt annually. At the intermediate input level an unburnt fallow (or possibly its equivalent as a ley) could be assumed. These values may be attributed to ferralsols and/or acrisols in the rain forest zone and to luvisols in the savanna zone.

On the basis of maintaining soil carbon levels, the following constraints to the cultivation factor in the warm tropics may be set:

Low input level:

| | | |
|---|---|---|
| Rain forest zone | (ferralsols/acrisols) | R = 14 - 55% |
| Savanna zone | (luvisols) | R = 4 - 23% |

Intermediate input level:

| | | |
|---|---|---|
| Savanna zone | (luvisols) | R = 10 - 43% |

Table 4.2 GAINS AND LOSSES OF SOIL HUMUS CARBON IN RAIN FOREST AND SAVANNA ENVIRONMENTS

| Environment (in warm tropics) | Loss during cultivation kg/ha/yr | Gain during fallow kg/ha/yr | Years of fallow to restore loss in 3 years cultivation | Cultivation factor R% |
|---|---|---|---|---|
| A. Soil carbon at 75 percent of natural equilibrium level | | | | |
| Rain forest | 1730 | 280-700 | 7.5-19 | 14-29 |
| Savanna (burnt annually) | 1930 | 75-190 | 30-70 | 4-9 |
| Savanna (no burn) | 1930 | 190-470 | 12-30 | 10-25 |
| B. Soil carbon at 50 percent of natural equilibrium level | | | | |
| Rain forest | 1170 | 560-1400 | 2.5-6 | 33-55 |
| Savanna (burnt annually) | 1280 | 150-380 | 10-26 | 10-23 |
| Savanna (no burn) | 1280 | 370-940 | 4-10 | 23-43 |

Source: based on data in Nye and Greenland (1960), Nye and Stephens (1962), Bernhard-Reversat (1975) and de las Salas and Fölster (1976).



Table 4.3 GAINS AND LOSSES OF SOIL NITROGEN IN RAIN FOREST AND SAVANNA ENVIRONMENTS

| Environment (in warm tropics) | Loss during cultivation kg/ha/yr | | | Gain during fallow kg/ha/yr | | | Cultivation factor R% | | |
|---|---|---|---|---|---|---|---|---|---|
| | High | Low | Typical | High | Low | Typical | Worst | Best | Typical |
| Rain forest zone | 400 | 100 | 200 | 125 | 70 | 100 | 15 | 55 | 33 |
| Savanna zone | 200 | 50 | 100 | 80 | 25 | 50 | 11 | 62 | 33 |

Source: based on data in Bartholemew (1977), Jones and Wild (1975) and Greenland (1977).

### 4.4.2 The nitrogen cycle

The nitrogen cycle is the most complex of the nutrient cycles. The basic model given by Frissel (1977), omitting livestock components, involves 4 stores, 3 external sources or sinks and 17 flows. The equation given by Greenland (1977) was 9 variables, but this refers only to losses from or gains to the soil-vegetation system as a whole, before consideration of transfers between plant, litter and soil.

Only a simple comparison between gross losses during cultivation and gains during fallow have been found to be practicable. Representative values for the two major environments of the lowland tropics are given in Table 4.3.

On the basis of maintaining soil nitrogen levels, the following constraints to the cultivation factor in the warm tropics may be set:

Low input level:

| | | |
|---|---|---|
| Rain forest zone | (ferralsols/acrisols) | R = 15 - 55%, typically 33% |
| Savanna zone | (luvisols) | R = 11 - 62%, typically 33% |

## 4.5 DATA ANALYSIS

### 4.5.1 Preparation of data bank

All of the data for Africa and Asia, together with a limited number of published records for America, were codified and put into a computerized data bank. Each card-punched record consists of two parts:

1. Site information Site number; latitude, longitude, country, region; major climatic division, growing period group, FAO soil unit; reference number of source publication, author, year, abstract year and number (Soils and Fertilizers), and type of study. For questionnaire responses, information on source is replaced by name of institution responding.

2. Information relevant to the rest period requirement Codified data on one of the following:

   - observed cultivation practices, with average cultivation factor and estimated soil degradation status;
   - observed soil changes, following years of cultivation or fallow; changes in C, N, K, P and Ca;
   - Carbon cycle, stores and flows
   - Nitrogen cycle, stores and flows
   - General observations
   - Questionnaire response, including observed years of cultivation and fallow/ley, soil degradation status, and estimated cultivation factor for no degradation.

Where one publication yielded information of more than one unit, additional pairs of site+information cards were prepared.

All such records were then sorted into numerical order, first by major climatic divisions and then successively by growing period groups and soil units; the soils, however, were put not into numerical order but into an order of presumed decreasing rest period requirements, as estimated on a priori grounds. Thus all records of a particular type, e.g. observed practices, are grouped together for each climate-soil combination. The records were read and printed out by a program called FALLOW. Space does not permit full reproduction but short extracts are given as Appendix B and the full data is deposited with FAO in Rome.

Next, summary cards were prepared. These give:

- Simplified site information (latitude, longitude, continent)
- Type of evidence (questionnaire response, observed practices, nutrient cycling study, agronomic experiment)
- Input level, climate and soil type
- The best estimate of the cultivation factor, R, based on the record concerned
- A weighting factor, basically 1.0 but higher or lower according to a subjective estimate of the importance and reliability of the record concerned.

These summary cards were then sorted into a somewhat different order to the basic records. The different types of evidence were pooled at this stage. The three input levels were separated, then the cards arranged as before by climate and soil. The summary cards were read and printed out by a program called FALSUM.

Thus the printout of FALSUM commences with all evidence, of whatever source and type, on the combination

I1 1 - 1 250 F

that is, input level I1, low; major climatic division 1, warm tropics; growing period group 1, rain-forest zone; and soil type 250 F, ferralsols (undifferentiated). This is succeeded by evidence on the cultivation intensities for orthic, xanthic and humic ferralsols, followed by the acrisols. On completing all soils in the rain-forest zone the data continues with records for ferralsols in the savanna zone, still at the low input level. After all climates and soils at this input level have been listed, there follow similar listings for each of the intermediate and high input levels.

The purposes served by codifying and classifying the data in this way are first, to convert information of all types into the form required, namely data relevant to the cultivation factor; and secondly to sort and re-aggregate the data such that all records for each combination of input level, climate and soil type are brought together.

Approximately 550 estimates of the cultivation factor are listed in the output to FALSUM. Most numerous are 28 records for Il, 1 - 1 251 Fo, orthic ferralsols in the lowland rain-forest zone, and 23 records for Il, 1 - 2 195 Lf, ferric luvisols in the savanna zone, both at the low input levels. There are many climate-soil combinations with only two, one or no records.

### 4.5.2 Derivation of best estimates for the cultivation factor

From a basis of the listings of evidence arranged by input level, climate and soil unit, best estimates were obtained in three stages.

(a) Subdivision of main soil groups The data were inspected to see whether any individual soil units differed substantially from the remainder of values for the main soil group. For example, at the low input level the humic ferralsols had substantially higher values than other ferralsol units. The evidence was only sufficient to justify such division of the main soil groups in a few instances.

(b) Best estimates for individual input level-climate-soil combinations The R values for each input level-climate-soil combination were tabulated in the manner illustrated in Table 4.4. These are of various forms, ranging from 'greater than' to 'considerably less than' the listed R value. Table 4.4A includes the limits set by the carbon and nitrogen cycles. Most of the values listed under 'greater than or equal to' refer to records of observed practices which are believed not to be causing soil degradation. Values under 'less than' include both published reports and questionnaire responses in which degradation or low-level equilibrium was occurring. The value under 'considerably less than' refers to an experiment in continuous cultivation of upland rice in which yields fell rapidly to near-zero.

The values in Table 4.4A can be resolved at a best estimate for R of 25 percent; this agrees with values having combined weights of 32 and contravenes values with weights of 4. Table 4.4B can be resolved equally at R = 35 or 40 percent, so this range was carried forward to the next stage.

Similar tables were constructed for each climate-soil combination at each input level. Many combinations contained considerably fewer values than those illustrated. In each case a best estimate of the cultivation factor was made, together with the weight of data contributing to it.

(c) Interpolation and extrapolation of values The estimates obtained in the previous stage, together with their weights, were then written into tables showing all climate-soil combinations. Three such tables were constructed, one for each level of inputs.

These tables included missing values, together with cases in which a range of percentages had been brought forward. These instances were resolved on the basis of intrinsic properties of climates and soils, and consequent deductions of relative needs for rest periods.

For the three growing period groups of the warm tropics the data was relatively complete at all three input levels. The few missing values were filled in by comparison, and single values selected where ranges had initially been given.

Table 4.4 DATA MATRICES FOR ESTIMATION OF THE CULTIVATION FACTOR

A. Low input level, warm tropics, rain forest zone, ferralsols (excluding humic ferralsols)

| Cultivation factor, R% | | | | | |
|---|---|---|---|---|---|
| Greater than | Greater than or equal to | Approximately equal to | Less than | Less than or equal to | Considerably less than |
| 14 | 17 | 33 | 55 | | 100 |
| 15 | 23 | 50 | 55 | | |
| 9 | 21 | 7 | 38 | | |
| | 22 | 10 | 29 | | |
| | 17 | 30 | 50 | | |
| | 20 | (40) | 50 | | |
| | 27 | | 100 | | |
| | 23 | | 20 | | |
| | 7 | | 62 | | |
| | 29 | | (9) | | |
| | 7 | | (29) | | |
| | | | (36) | | |

Best estimate R = 25% (weight 41)

B. Low input level, warm tropics, rain forest zone, luvisols

| Cultivation factor, R% | | | | | |
|---|---|---|---|---|---|
| Greater than | Greater than or equal to | Approximately equal to | Less than | Less than or equal to | Considerably less than |
| 4 | 40 | 20 | 50 | 23 | |
| 11 | 23 | 50 | | 62 | |
| | 21 | 33 | | 100 | |
| | 40 | 38 | | 40 | |
| | 25 | 33 | | (100) | |
| | 20 | 50 | | (83) | |
| | 75 | 75 | | (20) | |
| | 12 | 12 | | | |
| | 43 | 38 | | | |

Best estimate R = 35 - 40% (weight 39)

Key: 25 Weight over 2, 25 Weight 2, 25 Weight 1, (25) Weight 0.5.

For other major climatic divisions the data was more sparse. Where values existed, these were taken as reference points. Many values, however, were inserted by comparison with corresponding environments of the warm tropics.

Finally the values for corresponding environments at the three inputs were compared and a limited number of adjustments made to achieve consistency.

It should be stressed that throughout these stages of completion of the results, priority was given to original estimates of the cultivation factor, provided that these had a weight of at least 2, i.e. came from two independent sources.

## 4.6 DATA ANALYSIS IN THE STUDY OF SOUTH AND CENTRAL AMERICA

The method used by the consultant for the America study did not employ a computerized data bank but was otherwise similar in principle. All estimates for the cultivation factor, in each major climatic division, growing period group and for individual soil units, were written into three large tables, one for each level of inputs. These tables contain over 600 estimates of the cultivation factor, of which more than half are for the warm tropics.

Missing values were then completed in the same manner as in the Africa-Asia study, by consideration of intrinsic properties of climate and soils and hence relative rest period requirements.

The resulting tables were then simplified. It was again found that the data available was rarely sufficient to justify separation of main soil groups into their individual soil units. An exception is the separation of dystric from eutric nitosols.

## 4.7 COMPARISON OF VALUES FOR AFRICA, ASIA AND AMERICA

The values for the cultivation factor obtained in the study of South and Central America were found to be systematically lower than those obtained in the study of Africa and Asia. This applies in all climates and at all input levels, although most noticeably at the level of low inputs. Possible reasons for this are discussed in Section 6.1.

After much consideration it was decided to take compromise values as the basis for the main presentation of results, as to give pairs of values would produce undue complication. As this course of action necessarily results in a loss of information, the original results for the two studies are given in Appendix C. The choice of which set of values should be used or quoted for particular purposes is left to the discretion of the user. Thus for the main assessment to which this study is contributory, it will be possible:

(i) To select one only of the two sets of values.

(ii) To use values for each continent derived from data for that continent.

The procedure adopted for obtaining the compromise values for each input level-climate-soil combination is as follows:

1. Where only one of the studies gives a value for a particular combination, that value is given unmodified.

2. Where either of the studies gives a range of values, that closest to the other study is taken as a starting point.

3. Where the two initial values differ by a multiple of 10 percent, the compromise value is half way between; e.g. 30 and 40 are combined as 35. Where the two initial values differ by 5, 15, 25 etc. percent, the compromise value is taken slightly closer to that from the Africa/Asia study; e.g. 35 from America and 50 from Africa/Asia is given as 45.

## 4.8 MAXIMUM CULTIVATION FACTOR

Even at the high input level, it will rarely be good farming practice to grow an annual crop every single year. Persistent or ineradicable weeds, severe attacks of plant diseases or simply the requirements of a flexible, integrated farming system are likely to require an occasional period of non-cultivation. What is stated in published work and questionnaire responses to be 'continuous cultivation', and recorded in the data bank as R = 100, should usually be interpreted as nearly continuous.

Hence the highest value of the cultivation factor given for any climate-soil combination, at all input levels, has been set at R = 90.

# CHAPTER 5

## RESULTS

### 5.1 INTRODUCTION

Values of the cultivation factor R for the three input levels are given in Tables 5.1, 5.2 and 5.3. Only those climate-soil combinations that are of substantial extent, or for which some evidence was obtained, are included in these tables. The manner in which it is suggested that other soil units should be treated, based on their intrinsic properties, is given in Table 5.4.

The results given in these tables are compromise values, derived from those obtained from the initial studies of Africa/Asia and America. The original values for the two studies are given in Appendix C and a discussion of the differences between them in Section 6.1.

A general point which may be re-emphasized is that the major climatic division of the warm tropics occupies well over half of the potential arable land within the study area, and a high proportion of the data is derived from this climatic division. The results for the warm tropics are therefore substantially more firmly based than those for other climates.

The results will be discussed in two parts, first by input levels and secondly by soil types.

### 5.2 LOW LEVEL OF INPUTS

At the low level of inputs, corresponding to 'traditional' farming methods, the soil when not cultivated is left to be colonized by natural vegetation. Moreover, fallowing is the only means available for restoring to the soil the losses it has incurred during cultivation. It is therefore correct, at this level of inputs only, to speak of the fallow period requirement.

The results (Table 5.1) rest on two major pillars: ferralsols with acrisols in the rain forest zone and luvisols in the savanna zone. These two environments are extensive, agriculturally important and have yielded by far the most data; for the entire study area the values given rest on over 70 sources in the former and over 50 in the latter. The original data matrices have been given in Table 4.1-2.

Within the lowland rain forest zone, no distinction could be found between rest period requirements for ferralsols and acrisols. This no doubt partly results from the difficulty in distinguishing between these soil types; thus many soils which are assumed on casual inspection to be ferralsols have proved on careful examination to be acrisols. In the Africa/Asia study the evidence points to R = 25, or 1 year of cultivation in every 4, as the maximum acceptable ratio; for America, R = 5-10, or 1-2 years of cultivation in every 20, is suggested. The compromise value is R = 15 for ferralsols and acrisols in general, with two exceptions: R = 5 for acric ferralsols, based on data from the cerrado phase in South America, and R = 50 for humic ferralsols and humic acrisols.

Table 5.1 CULTIVATION FACTORS. INPUT LEVEL 1: LOW

| Major climatic division | Warm tropics | | | Cool tropics | | Warm subtropics | Cool subtropics | Medi-terranean | Temperate |
|---|---|---|---|---|---|---|---|---|---|
| Growing period, days | Rain forest zone 270-365 | Savanna zone 120-269 | Semi-arid zone 75-119 | Rain forest zone 270-365 | Savanna zone 120-269 | All | All | All | All |
| R, Q Regosols and Arenosols | 10 | 15 | 20 | 20 | 25 | 25 | 35 | 35 | - |
| F Ferralsols | 15 | 15 | 20 | 20 | 35 | 35 | 25 | 50 | - |
| Fa | 5 | | | 5 | | 5 | | | |
| Fh | 50 | | | | | | | | |
| A Acrisols | 15 | 15 | 20 | 20 | 25 | 35 | 25 | 50 | - |
| Ah | 50 | | | | | | | | |
| L Luvisols | 25 | 30 | 35 | 30 | 35 | 40 | 50 | 50 | 50 |
| B Cambisols | 35 | 50 | 40 | 40 | 50 | 75 | 55 | 35 | - |
| N Nitosols Nd | 25 | 30 | 40 | 45 | 60 | 75 | 80 | 40 | - |
| Ne | 40 | 55 | 75 | | | | | | |
| V Vertisols | 40 | 55 | 45 | 50 | 60 | 55 | 80 | 50 | - |
| J, G Fluvisols and Gleysols | 60 | 70 | 90 | 90 | 75 | 90 | 90 | 75 | - |

All values refer to the cultivation factor R, expressed as a percentage. For definition see Section 2.3.2.

Table 5.2 CULTIVATION FACTORS. INPUT LEVEL 2: INTERMEDIATE

| Major climatic division | Warm tropics | | | Cool tropics | | Warm subtropics | Cool subtropics | Medi-terranean | Temperate |
|---|---|---|---|---|---|---|---|---|---|
| Growing period, days | Rain forest zone 270-365 | Savanna zone 120-269 | Semi-arid zone 75-119 | Rain forest zone 270-365 | Savanna zone 120-269 | All | All | All | All |
| R, Q Regosols and Arenosols | 30 | 35 | 45 | 40 | 45 | 50 | 50 | 45 | - |
| F Ferralsols | 35 | 35 | 40 | 40 | 60 | 75 | 60 | 70 | - |
| Fa | 10 | | | | 10 | 10 | | | |
| A Acrisols | 40 | 35 | 60 | 40 | 45 | 60 | 55 | 70 | - |
| L Luvisols | 50 | 50 | 55 | 50 | 55 | 60 | 65 | 60 | 60 |
| B Cambisols | 65 | 60 | 60 | 70 | 70 | 90 | 70 | 65 | 40 |
| N Nitosols | 55 | 80 | 70 | 70 | 80 | 90 | 75 | 55 | - |
| V Vertisols | 70 | 75 | 75 | 70 | 75 | 80 | 80 | 70 | - |
| J, G Fluvisols and Gleysols | 80 | 80 | 90 | 90 | 85 | 90 | 80 | 80 | - |

All values refer to the cultivation factor R, expressed as a percentage. For definition see Section 2.3.2.

Table 5.3

CULTIVATION FACTORS. INPUT LEVEL 3: HIGH

| Major climatic division | Warm tropics | | | Cool tropics | | Warm subtropics | Cool subtropics | Medi-terranean | Temperate |
|---|---|---|---|---|---|---|---|---|---|
| Growing period, days | Rain forest zone 270-365 | Savanna zone 120-269 | Semi-arid zone 75-119 | Rain forest zone 270-365 | Savanna zone 120-269 | All | All | All | All |
| R, Q Regosols and Arenosols | 50 | 65 | 50 | 60 | 75 | 75 | 65 | 50 | - |
| F Ferralsols | 70 | 70 | 75 | 75 | 80 | 80 | 75 | 90 | - |
| Fa | 60 | | | 65 | | 60 | | | |
| A Acrisols | 65 | 65 | 75 | 65 | 70 | 80 | 70 | 90 | - |
| L Luvisols | 70 | 75 | 75 | 75 | 80 | 80 | 80 | 85 | 70 |
| B Cambisols | 85 | 85 | 80 | 85 | 85 | 90 | 85 | 80 | 70 |
| N Nitosols | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 85 | - |
| V Vertisols | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | - |
| J, G Fluvisols and Gleysols | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 | - |

All values refer to the cultivation factor R, expressed as a percentage. For definition see Section 2.3.2.

Table 5.4 CULTIVATION FACTORS: OTHER SOIL TYPES

The soil groups listed below have been excluded from Tables 5.1-3 for one or more of the following reasons:

- Occurring only under growing periods of less than 75 days
- Non-arable or doubtfully arable
- Absent or of small extent in the study area
- Very limited information obtained

Where necessary for the main study, it is suggested they be allocated cultivation factors, at all levels of inputs, as follows:

| | | |
|---|---|---|
| Treat as B, Cambisols: | E | Rendzinas |
| | H | Phaeozems |
| | K | Kastanozems |
| | O | Histosols |
| | T | Andosols |
| | X | Xerosols |
| Treat as Q, Arenosols: | P | Podzols |
| Treat as G, Gleysols: | W | Planosols |
| No present in study area: | C | Chernozems |
| | D | Podzoluvisols |
| | M | Greyzems |
| Non-arable: | I | Lithosols |
| | S | Solonetz |
| | U | Rankers |
| | Y | Yermosols |
| | Z | Solonchaks |

If growing periods of 75-119 days are found to occur in the cool tropics, the soils may be allotted the same values as for 120-269 days.

Thus if annual crops are to be grown with low inputs on ferralsols and acrisols of the rain forest zone, long fallow periods, of at least 4 years to every one of cultivation, are needed.

For luvisols in the savanna zone the evidence from Africa and Asia centers equally strongly on R = 35 - 40, or cultivation for 2 years in every 5 or 6. The initial estimate for America is substantially lower, R = 20. Taking the compromise value, this climate-soil zone, probably the most important for the production of annual food crops, can withstand cultivation for about 1 year in 3 at the low input level.

Comparing these two major environments with others, the soil types of the warm tropics may be seen to fall into four groups. Ferralsols, acrisols, regosols and arenosols share a need for long fallow periods, with R values less than or equal to 20. Luvisols, cambisols and dystric nitosols require fallow periods longer than cultivation periods, R = 30-40 (25 in the rain forest zone); of the less extensive soils, andosols fall into this range. Eutric nitosols and vertisols have higher cultivation factors, close to R = 50 or cultivation 1 year in 2. Fluvisols and gleysols have low fallow period requirements, since they lack an erosion hazard and may be in receiving sites.

Fallow period requirements in the two growing period groups of the cool tropics are similar to or slightly lower than those for corresponding growing periods and soil types in the warm tropics.

In both the warm and cool subtropics fallow period requirements are lower. The ferralsols and acrisols can be cultivated for 1 year in 3 to 4 whilst some of the more fertile cambisols, nitosols and vertisols approach continuous cultivation.

Data for the Mediterranean (winter rainfall) climatic zone is sparse; a value of about R = 50 for most soils is suggested.

## 5.3 INTERMEDIATE LEVEL OF INPUTS

Under the farming systems corresponding to the intermediate level of inputs, rest periods may be either natural fallows or of a more productive nature. Some of the major nutrient deficiencies can be ameliorated by fertilizers, but limitations in the technical knowledge and/or financial resources of the farmer are such that the full range of modern farming techniques cannot be applied.

The results (Table 5.2) represent independent estimates of the cultivation factor at this input level, although many fall near to half way between values at the low and high levels. In the warm tropics the same four groups are apparent. Ferralsols, acrisols, regosols and arenosols have, with some exceptions, values of about R = 35, or cultivation for 1 year in 3. Acric ferralsols are again assessed at a lower value. Luvisols and cambisols can be cultivated somewhat more than half the time, R = 50-60, whilst nitosols (other than in the rain forest zone) and vertisols are assessed at R = 75, or cultivation for 3 years in 4. Fluvisols and gleysols approach continuous cultivation at this input level.

Results for other climatic zones follow a corresponding pattern, with results in the region of R = 50 for less fertile and R = 75 for more fertile soils.

## 5.4 HIGH LEVEL OF INPUTS

At the high level of inputs, rest periods will nearly always be grass-legume leys or other productive types of use and only rarely fallows. The critical question is no longer "How long is the rest period requirement?" but "Can this soil be cultivated continuously?"

In the original data listing, a high proportion of both questionnaire responses and implications for agronomic experiments suggest that continuous or nearly-continuous cultivation of annual crops is indeed possible. Whether, and in what circumstances, it may also be desirable is a question lying beyond the scope of the present enquiry.

The more fertile soil types nitosols and vertisols, are almost invariably considered to be able to support continuous cultivation, and the luvisols and cambisols usually so. The upper limit of R = 90 (p. 32) is applied to all soils.

For the ferralsols and acrisols there is some variation of view. In the Africa/Asia study, 11 of the items of data (mainly questionnaire responses) suggest continuous cultivation is possible, whilst three separate experiments and two questionnaire responses indicate that this is not so. In the America study the ferralsols were assessed at R = 65 and the acrisols at R = 50. As a compromise between such viewpoints, these soils have been allotted values of R = 65-75, or cultivation of between 2 years in 3 and 3 years in 4.

## 5.5 RESULTS BY CLIMATE AND BY SOIL TYPE

### 5.5.1 Climates

In the rain forest zone of the warm tropics, i.e. the area with a growing period of over 270 days, rest periods are needed to counteract intense leaching of nutrients, rapid oxidation of organic matter, a strong tendency towards acidification, a high danger of water erosion, considerable hazards from pests and diseases, and rapid growth of weeds. The more sandy and/or permeable soils are particularly susceptible to leaching and acidification, the less permeable to erosion, but all soils to weed growth. Among the many reasons given for abandonment of shifting cultivation plots in this zone, that of weed growth is the most frequently mentioned.

With low inputs, a fallow period longer than cultivation is required on all soils except gleys. With high inputs, some experimental attempts at continuous cultivation have encountered difficulties on the ferralsols and acrisols. Although research is continuing, there is at present no management system for continuous arable use that can be confidently recommended in this zone.

In the savanna zone, all of the aforementioned hazards are present but at lower intensities. In particular, leaching intensity and the problem of weeds are less severe, whilst problems associated with moisture deficiency are not severe. One respect in which this zone is less favoured than the rain forest is the lower efficiency of natural fallows, consequent upon slower plant growth caused by the dry season. It is for this last reason that the fallow period requirements under low inputs are generally as high as for the rain forest zone. The lesser intensity of hazards is set against to lower efficiency of natural fallows.

Under high inputs the position in the savanna zone is more favourable. Many soils can be and are cultivated nearly continuously without serious degradation. In particular, for the widespread luvisols of this zone, a variety of management systems at high intensities of cultivation are available.

In the semi-arid zone, the relative intensities of hazards is very different. Oxidation of limited organic matter supplies remains a problem, weeds, pests and diseases cause somewhat less severe difficulties, whilst leaching is no longer serious. A new set of hazards arises related to the low rainfall: moisture availability and wind erosion. One of the standard 'dry farming' techniques, even on moisture-retentive soils such as vertisols, is for there to be fallowing for one whole year in order to store subsoil moisture for the next year's crop. Sometimes this is not a regular alternation but is varied according to the year-to-year exigencies of rainfall.

It is for reasons of moisture availability that at the low input level, most soils in this zone have been held to a cultivation factor of 50 or less. With high inputs this problem can be ameliorated, although by no means eliminated under rain-fed farming, through use of drought-resistant varieties.

The cool tropics are of considerably smaller extent and many such areas are mountainous. Many problems are similar to those of corresponding lowland environments but oxidation of organic matter is slower. Rest period requirements as indicated by the data differ less as between cool and warm tropics than had been expected on a prior grounds.

In the warm and cool subtropics with summer rainfall, soil problems and the nature of farm management differ appreciably. Shifting cultivation is not common, although limited use of fallowing is still a part of traditional farming systems. With low inputs, more than half the total farming cycle is allocated to fallow only on the less fertile soils. Under high inputs, soils are cultivated almost continuously.

As already noted, the results given for the subtropics with winter rainfall, of Mediterranean zone, are based on very limited evidence and should be regarded as tentative. The extent of the temperate zone within the study area is small.

### 5.5.2 Soil units

Characteristics of individual soils significant to their rest period requirements will be discussed in the order in which they are listed in Tables 5.1-3. This is followed by shorter notes on the remaining soil units.

REGOSOLS (R) AND ARENOSOLS (Q)

Significant characteristics:

- high sand content;
- low organic matter levels;
- low nutrient content;
- few or no reserves of weatherable minerals;
- rapid permeability therefore high susceptibility to leaching;
- low available water capacity.

Annual cultivation leads to rapid loss of the limited organic matter and with it most of the inherent nutrient content. Rapid leaching occurs in more humid climates. Drought hazard is serious in the semi-arid zone, where such soils are unfortunately widespread.

At the low input level, fallowing is relatively slow to restore organic matter, owing to the lack of clay particles on which to bind the organic colloids. Fallowing to build up subsoil moisture is practised in parts of the semi-arid zone. Very long fallows, of the order of 20 years, have been reported from some regions. There is a problem in giving a single R value in that fallow period requirements, if cassava is grown, are substantially less than where dietary preference or other reasons lead to the growing of maize or sorghum.

Moderate fertilizer applications under the intermediate level of inputs substantially improve the productivity of these soils. Heavy applications, however, may not be economic owing to leaching losses, and a substantial non-arable element in the rotation is still desirable.

FERRALSOLS (F)

Significant characteristics:

- Very low supply of available plant nutrients;
- strong acidity and high in active aluminium;
- very low levels of available phosphate;
- practically no reserves of weatherable minerals;
- topsoil organic matter easily lost;
- structure often more stable than in acrisols.

Annual cultivation leads to lowering of organic matter, nutrient depletion, increased fixation of phosphorous and growing imbalance in trace element availability.

Under low input farming, these soils are little used in America, and then only for cassava and with long fallows. Use is more widespread in other continents and R values of up to 20 or 25 appear to be tolerable. With high inputs, possibly including liming as well as heavy dressings of fertilizer, the depths and stable structure of these soils become assets. Limited rest periods are still needed to control pests and diseases and to aid in nutrient balance.

It should be noted that there was formerly a tendency to assign all freely-drained red to yellow soils of the humid tropics to the ferralsol class, and some areas earlier as ferralsols have on proper examination proved to be acrisols.

ACRISOLS (A)

Significant characteristics:

- Low to very low supply of available plant nutrients;
- strong acidity, low in calcium, high in active aluminium;
- topsoil organic matter easily lost;
- structure weak, breaks down readily;
- argillic B horizon may slow down internal drainage;
- low in some trace elements.

Annual cultivation leads to lowering of organic matter, structural degradations, deficiencies in major plant nutrients (including through fixation) and some trace elements; if continued after organic matter falls, surface compaction and reduced permeability in the B horizon may lead to water erosion.

With low inputs, these require a long fallow period, to restore organic matter, improve structural condition and build up nutrients. A regime of 1-2 years cultivation followed by 20 or more years fallow (R = <5-10) is common in America, although where pressure on land requires up to R = 25 seems acceptable in Africa and Asia. Intermediate inputs are by no means sufficient to overcome nutrient deficiencies; only on small 'garden' areas, with high applications of organic residues, are such farmers able to use these soils continuously. At the high input level, some land development companies have attempted continuous cultivation but it has usually been found that rest periods under grass or green manure crops are necessary. There is not yet sufficient experience of the effects of continuous modern farming on these soils, and it may prove that the value given of R = 65 is too high for long-term stability.

LUVISOLS (L)

Significant characteristics:

- Inherent nutrient content moderate;
- organic matter low to moderate, lower where A horizon sandy;
- structure weak in topsoil, moderate but often unstable in argillic horizon.

These soils are widespread in the savanna zone, usually as ferric luvisols (ferruginous soils in other classification systems). They constitute one of the main soils for production of maize, sorghum, groundnuts and other annual food crops. This soil group can in some respects be regarded as a mid-point in the spectrum from poor to good tropical soils, being free of the more severe hazards found in ferralsols, acrisols and the very sandy profiles but lacking some of the more favourable properties of soils such as eutric nitosols.

At the low input level a fallow of about 2 years in 3 is necessary to maintain the soil in a productive state; in practice this has not uncommonly been exceeded and the soils brought to a state of low level equilibrium, with degraded soil properties and low crop yields. The soils respond well to modest fertilization or manuring, permitting a substantial rise in cultivation intensity at the intermediate input level. There was a wide difference of assessment for this soil between the two contributing studies; for the savanna zone, substantial evidence from the Africa/Asia study indicated a value of about R = 65, whilst the assessment for America was R = 30.

With high inputs it has been experimentally demonstrated that annual cropping for at least 3 years out of 4 can be sustained in the long term.

CAMBISOLS (B)

This soil group, the primary purpose of which is to cover non-argillic brown earths of temperate climates, encompasses a variety of soils in tropical and sub-tropical regions. These range from soils of shallow to moderate depth on cooler upland regions in South America to areas of older alluvium on the Ganges flood-plain of India. As such it is difficult to state their significant characteristics, other than that of lacking extremes, e.g. of sandiness, acidity. Organic matter status is generally moderate to good.

Assessments of the cultivation factor are slightly above those for luvisols at all input levels. With high inputs, nearly continuous cultivation is possible.

NITOSOLS (N)

Significant characteristics

- Plant nutrient supply moderate to high, higher in eutric nitosols;
- dystric nitosols have problems of acidity and consequent nutrient fixation;
- well-developed structure, moderately stable;
- reserves of weatherable minerals moderately high;
- organic matter levels generally above those of other freely-drained soils in a given climatic zone;
- highly available water capacity;
- moderately high erosion hazard in humid climates.

The nitosols are among the most fertile of freely-drained soils of the humid tropics, and in some areas support high population densities. At the low input level there is a significant difference of assessment between dystric and eutric nitosols, although the former predominates in the rain-forest zone and the latter in the semi-arid zone. This difference may well persist at higher input levels although there has not been found sufficient evidence to justify different R values.

At the low input level the eutric nitosols of the savanna and semi-arid zones can be cultivated for at least 1 year in 2, whilst the dystric nitosols of the rain-forest zone share some of the degradation hazards of luvisols and acrisols. Nitosols respond well to inputs, can be continuously cropped under high inputs and nearly so with intermediate inputs.

VERTISOLS (V)

Significant characteristics:

- Good supply of nutrients;
- relatively high organic matter content;
- montmorillonitic clay fraction, leading to very low permeability when wet and a severe water erosion hazard;
- serious cultivation problems, because soil hard when dry and very sticky when wet;
- moderately high available water capacity.

Vertisols have favourable chemical properties but severe physical problems, as a consequence of which their use under traditional farming systems varies. In some areas they are relatively intensively cultivated whilst in others they are left to pasture. In the semi-arid zone, fallowing in alternate years for moisture conservation may be practised. On balance, an R value of close to 50 is suggested.

The wider range of farming techniques available at the intermediate and high input levels can ameliorate some of the physical problems, e.g. by stabilising the water table, and high intensities of cultivation become possible.

FLUVISOLS (J) AND GLEYSOLS (G)

These two soil types constitute a special case, in that they occur on level land and hence swamp rice can be grown in more humid climates. There are no erosion problems and chemical fertility is aided by the high water table or location in receiving sites. Some properties, especially texture, vary widely.

Under low inputs, some fallowing is necessary, to control weeds, pests and diseases. With intermediate and high inputs there is no requirement for a rest period.

OTHER SOIL TYPES

RENDZINAS (E) are potential arable soils but of limited extent in the study area. Many occur on steep slopes and thus fall outside the scope of this enquiry. A questionnaire response for Papua New Guinea suggests R = 12 with low inputs but the estimates for America indicate higher values, similar to those for cambisols.

PHAEOZEMS (H) and KASTANOZEMS (K) occur in the America study area, but very few remain under low inputs. R values similar to cambisols are suggested for all levels.

HISTOSOLS (O) are not wholly non-arable soils but their use for annual crops is confined to special local circumstances and no generally-applicable cultivation factor can be assessed.

ANDOSOLS (T) are of limited extent and have very distinctive characteristics, notably high levels of active aluminium in the form of allophane, causing strong phosphorus fixation. There is considerable difference in their potential under low as against high inputs. The evidence available is not sufficient to differentiate the cultivation factors from those for cambisols, although they may be somewhat lower.

XEROSOLS (X) are normally found where growing periods are less than 75 days, but where identified in the 75-119 day zone may be treated as cambisols.

Tropical PODZOLS (P) occur in two distinctive sites, but those at high altitudes fall within the cold tropics. Lowland podzols occur in the rain forest zone on sands. They are of doubtful value for cultivation at all, but if used should be assigned rest periods at least as long as those for arenosols.

PLANOSOLS (W) should normally be assigned the same cultivation factors as gleys; this applies in particular where they occur in South America. The substantial area in southern Africa shown on the Soil map of the World as planosols is in fact very dissimilar to gleys, and if practicable should be treated in the main project as cambisols.

CHERNOZEMS (C), PODZOLUVISOLS (D) and GREYZEMS (M) are absent or of very limited extent within the study area. If mapped areas are found they may be treated as cambisols.

LITHOSOLS (I), SOLONETZ (S), RANKERS (U), YERMOSOLS (Y) and SOLONCHAKS (Z) are regarded as non-arable.

# CHAPTER 6

# DISCUSSION

## 6.1 DIFFERENCES BETWEEN RESULTS BASED ON AFRICA/ASIA AND ON AMERICA

It has been noted earlier that the enquiry was intentionally conducted in the first instance as two independent studies, one of Africa and the other of South and Central America. These were carried out by different consultants. The Africa study was subsequently extended to Asia by the same consultant. Both studies were based on identical definitions and assumptions, but the sources used differed in balance, published work weighing more heavily in the Africa/Asia study and personal experience in the America study; questionnaire replies were only available for Africa and Asia.

With only few exceptions the values for the cultivation factor, R, found in the America study were found to be systematically lower than those from the Africa/Asia study. The full original results of the two studies are tabulated in Appendix C. The results given in Chapter 5 are compromise values, obtained in the manner described in Section 4.5.4. It is, however, of some interest that such a systematic difference should arise, and a brief discussion of possible reasons follows.

Whilst the differences between the two sets of values extend to most climate-soil combinations, comparison between them can be simplified in two respects. First, a high proportion of the data refer to the warm tropics, many values for other major climatic divisions being derived in whole or part by comparison. Secondly, if the differences can be resolved at the low and high level of inputs, values at the intermediate level may be adjusted appropriately.

Table 6.1 therefore sets out the two sets of data for the warm tropics, at low and high input levels, in comparative form. No-one would suppose that estimates at this level of generalization are accurate to within less than $\pm 10$ percent; hence differences of up to 10 percent may reasonably be considered as 'agreement' whilst those of up to 20 percent could still be reconciled by a compromise value differing only 10 percent from each. The pairs of values in the table may be grouped as follows:

| Percentage difference | | Number of values: Low inputs | Number of values: High inputs |
|---|---|---|---|
| 0-10 | Near-agreement | 12 | 14 |
| 11-20 | Minor difference | 6 | 3 |
| 21-30 | Substantial difference | 2 | 6 |
| 31-40 | Substantial difference | 4 | 1 |
| | | 4 | 3 |
| | | 28 | 27 |

Table 6.1 CULTIVATION FACTORS. COMPARISON OF AFRICA/ASIA STUDY WITH AMERICA STUDY

| | | INPUT LEVEL 1: LOW | | | INPUT LEVEL 3: HIGH | | |
|---|---|---|---|---|---|---|---|
| Major climatic division | | Warm tropics | | | Warm tropics | | |
| Growing period, days | | 270-365 | 120-269 | 75-119 | 270-365 | 120-269 | 75-119 |
| Q Arenosols | a[1/] | 10 | 15 | 25 | 50 | 65 | 50 |
| | b | 5 | 5 | 5 | 50 | 60 | 40 |
| R. Regosols | a | 10 | 15 | 25 | 50 | 65 | 50 |
| | b | 15 | 15 | 15 | 80 | 80 | 80 |
| F Ferralsols[2/] | a | 25 | 25 | - | 75 | 75 | - |
| | b | 5 | 5 | 10 | 60 | 65 | 70 |
| A Acrisols | a | 25 | 25 | - | 75 | 75 | - |
| | b | 5 | 5 | - | 50 | 55 | - |
| L Luvisols | a | 25 | 35 | 50 | 80 | 90 | 90 |
| | b | 20 | 20 | 20 | 55 | 55 | 60 |
| B Cambisols | a | 35 | 65 | 50 | 90 | 90 | 90 |
| | b | 30 | 30 | 25 | 80 | 80 | 70 |
| N Nitosols | a | 25 | d:30 e:75[3/] | 75 | 90 | 90 | 90 |
| | b | 25 | d:30 e:40 | 40 | 85 | 90 | 90 |
| V Vertisols | a | - | 50 | 50 | 90 | 90 | 90 |
| | b | 40 | 40 | 40 | 90 | 90 | 90 |
| G Gleysols | a | 60 | 90 | 90 | 90 | 90 | 90 |
| | b | 50 | 50 | - | 90 | 90 | - |

1/ a Africa/Asia Study
b America Study

2/ Excluding acric and humic

3/ d: dystric, e: eutric

At the low input level the substantial differences are as follows:

1. For America, arenosols are given much lower values than regosols, whereas for Africa/Asia these are treated the same.

2. Ferralsols and acrisols are assumed to be cultivated 1 year in 20 in America, 1 in 4 in Africa/Asia. Note, however, the statement in the America report: "a crop of cassava may be taken in the second year" of a 1 in 20 cycle, which would convert the R value from 5 to 10 percent.

3. Luvisols, cambisols and eutric nitosols, in the savanna and semi-arid zones, are given substantially lower values in America.

4. Gleysols in the savanna zone are allotted 1 year in 2 fallow in America.

At the high input level, the differences are:

5. Regosols are assessed more highly in America, an exception to the general trend.

6. Ferralsols and acrisols are still assessed lower in America, although the difference is only one of cultivation 2 years versus 3 years in 4.

7. Luvisols are assessed at close to continous cultivation in Africa/Asia but only 1 year in 2 in America.

The two most important differences, in terms of area covered, concern the ferralsols with acrisols (2 and 6 above) and the luvisols and related soils (3 and 7 above).

Possible reasons for different findings are:

(i) Soils of the same classes differ as between continents. A number of observers who have seen both have remarked on the extremely dystrophic nature of South America soils as compared with their African counterparts. The cerrado phase is mapped only in America, and the assessment of acric ferralsols is explicity based mainly upon this phase.

(ii) Land pressure, and hence what are regarded as acceptable cultivation intensities, differ. On average, there is least land pressure in South America, more in Africa and most in Asia. Hence some communities in America assumed to be at the critical ratio may in fact still have a safety margin.

(iii) The methods or assumptions used in the two investigations differ. In the Africa/Asia study the maximum acceptable cultivation factors were intentionally sought.

There is probably an element of each of these reasons present.

## 6.2 SOME IMPLICATIONS OF THE RESULTS

### 6.2.1 The magnitude of differences in land productivity between input levels

It is common knowledge that the crop yields from improved methods, here called the intermediate level of inputs, are at least twice those from traditional farming, whilst yields from modern methods, or high inputs, are more than three times as high. In terms of maize, the yields to be expected from low, intermediate and high inputs are of the order of 0.6 to 1, 2 to 3, and 3 to over 5 tons per hectare respectively. The magnitude of these yield differences alone is sufficient to justify development expenditure on, and give results from, measures for improvement of farming methods.

When the differing rest period requirements at the three input levels are taken into consideration, these differences in land productivity are considerably magnified. This applies to nearly all soil units. For ferralsols in the rain forest zone, for example, the cultivation factors at low, intermediate and high input levels are respectively R = 15, 35 and 70. For luvisols in the savanna zone the corresponding values are R = 30, 50 and 75, whilst for more fertile soils such as eutric nitosols and vertisols the values are R = 55, 75-80 and 90.

The sustained land productivity from annual crops is obtained by multiplying the crop yield per year of cultivation by the R value expressed as a fraction, i.e. R = 15 percent expressed as 0.15. Hence, for example, if potential maize yields on ferralsols in the rain forest zone are taken as 1, 2 and 3 t/ha at the three input levels, the sustained potential of these soils is 0.15, 0.70 and 2.10 t/ha respectively. These are differences of nearly 5 and 3 times between successive input levels, or 14 times between low and high inputs.

It will be apparent from the examples quoted above, and from the results tables in Chapter 5, that the differences in productivity between different input levels are greatest on the least fertile soils. Thus very large differences apply to ferralsols, acrisols and arenosols in the warm tropics. For soils of moderate fertility, such as luvisols and cambisols, differences in rest period requirements between successively higher input levels have the effect of magnifying yield differences by about 1½ times at each step. For the most fertile soil units there is a similar effect as between low and intermediate inputs, but less difference induced by rest periods between the intermediate and high levels. Only for the special case of gleysols does this magnifying effect of the rest period requirement not operate so substantially.

The differences between rest period requirements at different input levels become somewhat less in cooler climates, although by no means negligible.

Thus the effects of rest period requirements upon potential land productivity from annual crops, and in particular on differences in productivity between low, intermediate and high input levels, are greatest on the least fertile soils.

### 6.2.2 Implications for the development of areas under shifting cultivation

There are differing views on the value and limitations of shifting cultivation as a system for utilizing tropical soils (FAO, 1974). What may be generally agreed, however, is that in many areas it is becoming difficult or impossible to continue the system, at least in its present form, owing to land pressure brought about by population increase. A search for practicable alternatives is therefore desirable.

In the present enquiry, much of the evidence relating to the low input level came from observations of shifting cultivation systems. It is these which are responsible for all of the low values of the cultivation factor, ranging from R = 30 down to as low as R = 5.

In most instances, data relating to the intermediate and high input levels came from different sites to those for low levels. Thus in the questionnaires, respondents often either left the intermediate and high level sections blank, stating there was no evidence available, or supplied no information on the low level on the grounds that it was no longer practised.

However, the system of climatic regionalization in terms of major climatic divisions and growing period groups, coupled with the soil units of the Soil Map of the World, provides a framework for identifying environmentally similar areas. Through the system of data analysis employed here, data concerning a particular input level derived from one source can be directly compared with data on other input levels from different sources (cf. Appendix B).

It is clear from such comparisons, as embodied in the results of the present study, that where farming systems can be transformed from the low to the intermediate input levels, a considerable reduction in rest period requirements is possible. As noted above, the reduction is greatest on the intrinsically least fertile soil types, and it is on these that shifting cultivation most frequently occurs. Thus if means can be found to raise input levels, there is the potential for a considerable saving in the land area needed to support a given population.

In order to enquire further into this subject, the next steps might be:

(i) to identify the major climate-soil environments in which shifting cultivation was practised;

(ii) to locate similar environments in which farming experience at the intermediate or high input levels was available;

(iii) to examine details of the inputs and management practices through which the lower rest period requirements at these levels were achieved.

## 6.3 REQUIREMENTS FOR RESEARCH

The greater part of the data employed in this enquiry is either inferential or tentative; very few studies specifically directed at the question at issue have been made. The firmest evidence has come from a very few long-term experiments, such as those at Yangambi (Zaire) and Samaru (Nigeria). Less certain is evidence from experiments of 5 years or under, since clear indications of the long-term effects of given agricultural treatments on the soil cannot be established within such a period.

The bulk of the evidence, however, has come from observations of actual farming practices, and here there is one component of considerable uncertainty. It is known that on most soils, rest periods of some duration are needed; and an approximate estimate of the relative lengths of cultivation and non-cultivation practised can usually be made. What is rarely known with any degree of certainty is the condition of the soil under such practices and whether it is in a steady state or undergoing degradation.

Evidence of this last type could be obtained by monitoring soil properties, under local farming practice, over a period of 10 years or more. It would be possible to achieve a substitution of space for time by sampling soils of known and differing cultivation histories within the same area. In this way, data obtained from the somewhat unrealistic circumstances of agricultural experimental work could be compared with that on soil response under actual farming practices.

It is unlikely that knowledge of soil rest period requirements can be substantially improved without research directed specifically at this question. Measures for this purpose are as follows:

(i) All major agricultural research stations should be encouraged to establish, or continue, long-term experiments in which a range of repeated cultivation/non-cultivation rotations is applied and the soil properties under each are monitored annually.

(ii) Research should be encouraged in the investigation of soil properties under actual farming practices, where possible comparing the past cultivation sequences and inputs on different plots belonging to the same soil type with the resulting soil conditions. In a few selected areas, such studies might be extended into a long-term soil monitoring programme.

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## APPENDIX A

### QUESTIONNAIRES

First version of questionnaire, as used in the Africa study.

Respondents were sent a covering letter, an explanatory sheet outlining the purposes of the enquiry and giving necessary definitions, three copies of the sheets for individual soil types and one copy of the sheet requesting general information.

FALLOW PERIOD REQUIREMENTS:

SOIL NO.

LOCATION AND ENVIRONMENT

Location (latitude and longitude or administrative district or name of town within region or name and location of experiment station)

Climate Mean annual rainfall, mm:
Number of dry months (< 50mm):
Altitude, m:

Soil Type (name in national or any international classification system or legend to FAO/Unesco Soil Map of the World)

ACTUAL AGRICULTURAL PRACTICES

At the low-input level how many years of cultivation and of fallow (or other non-cultivation) are normally practised?

Do you consider that at this ratio, the soil is in a long term steady state with respect to organic matter and nutrients, and meets the other conditions of the fallow period requirement? If not, what ratio do you estimate to be necessary to meet these conditions?

Is it probable that this soil can be maintained under continuous or nearly-continuous (> 3 years out of 4) cultivation at either the intermediate or high level of inputs? If not, what cultivation/fallow ratios are necessary at these levels?

RECOMMENDED AGRICULTURAL PRACTICES

Are there any crop rotations involving alternation between cultivation and fallow recommended for this soil by agricultural advisory services? If so, how many years of cultivation and of fallow, and to what level of inputs does this advice refer?

REFERENCES

Could you please give details of any publications which give information relevant to fallow period requirements, agricultural practices or nutrient cycling on this soil:

FALLOW PERIOD REQUIREMENTS:

GENERAL INFORMATION

OTHER SOIL TYPES

Apart from the soils for which detailed information has been given, are there any soil types in the country (or region) which can tolerate continuous or nearly-continuous cultivation at the low-input level? If so, which soil types and locations?

Are there any other soil types for which you can estimate fallow period requirements at the low-input level?

REFERENCES

In addition to those listed for specific soils, please give details of publications for the country which give information relevant to fallow period requriements. This could include:

- descriptions of actual agricultural practices
- government advisory service publications
- scientific accounts of long-term agronomic experiments

ANY OTHER COMMENTS?

Thank you very much for your kind help.

Second version of questionnaire, as used in the Asia study.

Respondents were sent a covering letter, an explanatory sheet outlining the purposes of the enquiry and giving necessary definitions, and three copies of the sheets for individual soil types.

REST PERIOD REQUIREMENTS:

SOIL NO.

LOCATION AND ENVIRONMENT

Name of region, town or experiment station:

Latitude: Longitude:

Altitude:

Climate Mean annual rainfall, mm:

Number of dry months (< 50mm):

Soil type Name in national or any international classification:

If known, equivalent in legend to FAO/Unesco Soil Map of the World:

PLEASE GIVE INFORMATION FOR AS MANY OF THE THREE INPUT LEVELS AS CAN BE ESTIMATED.

1. LOW INPUT LEVEL

A. At this input level, what are the usual agricultural practices? Years of cultivation: Years of fallow:

B. Do you consider that at this ratio, the soil is in a long term steady state with respect to organic matter and nutrients, and meets the other conditions of the fallow period requirement?

YES ☐ NO ☐

C. If the answer to B is "No", what would you estimate to be the necessary ratio? Years of cultivation: Years of fallow:

D. At this input level, are there recommendations for this soil by agricultural advisory services? Years of cultivation: Years of fallow:

E. Basis of your assessment (e.g. agronomic experiments, general experience):

2. INTERMEDIATE INPUT LEVEL

(Questions A to E, as above, were repeated.)

3. HIGH INPUT LEVEL

(Questions A to E, as above, were repeated.)

ANY OTHER COMMENTS?

Information given by:

## APPENDIX B  Extracts from the computerized data bank.

### 1. Extracts from "FALLOW", the basic data store

SITE INFORMATION AND SOURCE

| SITE | LAT | LNG | COUNTRY | LOCATION | MCD | GPG | SOIL | TYPE | REF.NO | AUTHOR | YEAR | ABSTRACT* | TYPE OF STUDY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 5 | -5 | IVORY CO | BANCO | 1 | 1 | 251 | FO | 7 | BERNHARD-REVERSA | 1977 | 78/3090 | NUTRIENT CYCLING |
| 10 | 5 | -5 | IVORY CO | YAPO | 1 | 1 | 251 | FO | 7 | BERNHARD-REVERSA | 1977 | 78/3090 | NUTRIENT CYCLING |
| 12 | 6 | 2 | W AFRICA | REPRESENT.VALUES | 1 | 1 | 251 | FO | 9 | NYE PH+GREENLAND | 1960 | 99/9999 | NUTRIENT CYCLING |
| 16 | 5 | -5 | IVORY CO | BANCO | 1 | 1 | 251 | FO | 11 | BERNHARD-REVERSA | 1975 | 99/9999 | NUTRIENT CYCLING |
| 17 | 5 | -5 | IVORY CO | YAPO | 1 | 1 | 251 | FO | 11 | BERNHARD-REVERSA | 1975 | 99/9999 | NUTRIENT CYCLING |
| 18 | 1 | 24 | ZAIRE | YANGAMBI | 1 | 1 | 251 | FO | 12 | JURION F+HENRY J | 1969 | 99/9999 | OBSERVED PRACTICES |
| 24 | 6 | -1 | GHANA | FOREST ZONE | 1 | 1 | 251 | FO | 15 | NYE PH+STEPHENS | 1962 | 99/9999 | REVIEW |
| 29 | 99 | 99 | TROPICS | FOREST ZONE | 1 | 1 | 251 | FO | 18 | BARTHOLEMEW WV | 1977 | 78/4328 | REVIEW |
| 32 | 6 | 6 | NIGERIA | BENIN | 1 | 1 | 251 | FO | 20 | NEWTON K | 1960 | 99/9999 | REVIEW |
| 33 | -4 | 20 | ZAIRE | CEN. CONGO | 1 | 1 | 251 | FO | 20 | NEWTON K | 1960 | 99/9999 | REVIEW |
| 34 | 9 | -13 | SA LEONE | FOREST ZONE | 1 | 1 | 251 | FO | 20 | NEWTON K | 1960 | 99/9999 | REVIEW |
| 46 | 7 | -1 | GHANA | DENSU BASIN | 1 | 1 | 251 | FO | 24 | SINGH K | 1961 | 61/1593 | CONTROLLED EXPERMT |
| 48 | 9 | -13 | SA LEONE | NJALA | 1 | 1 | 251 | FO | 25 | BRAMS E | 1971 | 72/1210 | CONTROLLED EXPERMT |
| 53 | 1 | 24 | ZAIRE | YANGAMBI | 1 | 1 | 251 | FO | 29 | DHOORE J | 1968 | 99/9999 | CONTROLLED EXPERMT |
| 63 | 1 | 24 | ZAIRE | YANGAMBI | 1 | 1 | 251 | FO | 36 | MALDAGUE ME | 1960 | 62/ 959 | OBSERVED SOILS |

*Soils and Fertilizers, year and no.

SITE INFORMATION: QUESTIONNAIRE

| SITE | LAT | LNG | COUNTRY | LOCATION | MCD | GPG | SOIL | TYPE | RESPONDENT |
|---|---|---|---|---|---|---|---|---|---|
| 3012 | 25 | 92 | BANGLDSH | HILL AREAS | 1 | 1 | 250 | F | FAO |
| 3017 | 3 | 113 | SARAWAK | COUNTRY IN GENRL | 1 | 1 | 250 | F | ANDRIESSE |
| 1019 | 6 | 4 | NIGERIA | IJEBU-ODE,OGUM | 1 | 1 | 251 | FO | IBADAN UNIV.AGRI |
| 1049 | 5 | 8 | NIGERIA | UMDIKE,UMUAHIA | 1 | 1 | 251 | FO | ROOT CR.RES.INST |
| 1054 | 8 | -11 | SA LEONE | KENEMA,E PROV. | 1 | 1 | 252 | FX | FAO |
| 3018 | -2 | 103 | INDNESIA | SUMATRA,JAMBI | 1 | 1 | 252 | FX | LRDC |
| 3013 | 24 | 90 | BANGLDSH | MADHUPUR,BARIND | 1 | 1 | 230 | A | FAO |
| 1021 | 8 | -12 | SA LEONE | MOYAMBA | 1 | 1 | 234 | AP | NJALA UNIV.SOILS |
| 3009 | -4 | 104 | INDNESIA | S SUMATRA,LAHAT | 1 | 1 | 231 | AO | FAO |
| 1011 | 5 | 6 | NIGERIA | BENIN-OWERRI | 1 | 1 | 232 | AF | IBADAN,IITA |
| 3021 | 7 | 81 | SRILANKA | RAHANGALA,UVA | 1 | 2 | 232 | AF | LAND USE DIVN |
| 1051 | 8 | -5 | IVORY CO | BOUAKE | 1 | 1 | 232 | AF | FAO BOUAKE |

Note: The convention "9, 99" etc. is used in indicate no data.

QUESTIONNAIRE RESPONSE: LOW INPUT LEVEL

| SITE | MCD | GPG | SOIL | CULTIVATION MIN | CULTIVATION MAX | CULTIVATION AVE | FALLOW/LEY MIN | FALLOW/LEY MAX | FALLOW/LEY AVE | RX AVE | DEG STS | RNO DEG | RECUMMENDED CUL | RECUMMENDED FAL | RECUMMENDED RX | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3012 | 1 | 1 | 250 F | 1 | 2 | 2 | 2 | 5 | 5 | 38 | 2 | 99 | 99 | 99 | 99 | SHORTENED F CAUSING DEGRADN. |
| 3017 | 1 | 1 | 250 F | 1 | 1 | 1 | 6 | 15 | 11 | 9 | 2 | 7 | 1 | 15 | 7 | LITTLE LAND BELOW 10 SLOPE. |
| 1019 | 1 | 1 | 251 FO | 1 | 3 | 2 | 3 | 7 | 5 | 29 | 2 | 10 | 99 | 99 | 99 | |
| 1049 | 1 | 1 | 251 FO | 2 | 2 | 2 | 3 | 4 | 4 | 36 | 2 | 30 | 2 | 3 | 40 | |
| 1054 | 1 | 1 | 252 FX | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 9 | 99 | 99 | 99 | 99 | USED FOR TREE CROPS. |
| 3018 | 1 | 1 | 252 FX | 1 | 2 | 2 | 99 | 99 | 30 | 7 | 1 | 99 | 99 | 99 | 99 | FALLOW IS RUBBER |
| 3013 | 1 | 1 | 250 A | 99 | 99 | 30 | 99 | 99 | 0 | 98 | 4 | 99 | 99 | 99 | 99 | V LOW YIELDS AT I1 |
| 1021 | 1 | 1 | 254 AP | 2 | 3 | 3 | 8 | 8 | 8 | 24 | 1 | 99 | 99 | 99 | 99 | FORMERLY F10 |
| 3009 | 1 | 1 | 251 AO | 1 | 3 | 2 | 10 | 12 | 11 | 15 | 1 | 99 | 99 | 99 | 99 | RECOMMENDED FOR TREE CROPS |
| 1011 | 1 | 1 | 252 AF | 1 | 30 | 99 | 1 | 15 | 99 | 99 | 9 | 99 | 99 | 99 | 99 | CONT CULTD WHERE POPN HIGH. |
| 3021 | 1 | 2 | 232 AF | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 9 | 38 | 99 | 99 | 99 | |
| 1051 | 1 | 1 | 252 AF | 2 | 3 | 3 | 6 | 8 | 7 | 26 | 2 | 24 | 99 | 99 | 99 | |
| 1053 | 1 | 1 | 252 AF | 3 | 3 | 3 | 10 | 10 | 10 | 25 | 2 | 15 | 99 | 99 | 99 | |
| 1059 | 1 | 2 | 232 AF | 99 | 99 | 99 | 99 | 99 | 99 | 38 | 4 | 99 | 99 | 99 | 99 | |
| 3010 | 1 | 1 | 233 AH | 99 | 99 | 99 | 99 | 99 | 99 | 99 | 9 | 99 | 99 | 99 | 99 | VOLCANO. INTERCROPPING COMMON. |

OBSERVED PRACTICES

| SITE | MCD | GPG | SOIL | INPUT LEVEL | CULTIVATION MIN | CULTIVATION MAX | CULTIVATION AVG | --FALLOW--- MIN | --FALLOW--- MAX | --FALLOW--- AVG | R% MEAN | DEGRDN STATUS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 1 | 1 | 251 FO | 1 | 1 | 3 | 2 | 4 | 16 | 10 | 17 | 1 |
| 12 | 1 | 1 | 251 FO | 1 | 2 | 2 | 2 | 2 | 12 | 5 | 29 | 2 |
| 18 | 1 | 1 | 251 FO | 1 | 3 | 4 | 3 | 12 | 14 | 12 | 23 | 1 |
| 24 | 1 | 1 | 251 FO | 1 | 1 | 3 | 2 | 5 | 10 | 7 | 21 | 1 |
| 32 | 1 | 1 | 251 FO | 1 | 2 | 2 | 2 | 6 | 8 | 7 | 22 | 1 |
| 33 | 1 | 1 | 251 FO | 1 | 2 | 3 | 3 | 12 | 50 | 15 | 17 | 1 |
| 34 | 1 | 1 | 251 FO | 1 | 2 | 2 | 2 | 7 | 9 | 8 | 20 | 1 |
| 71 | 1 | 2 | 251 FO | 1 | 99 | 99 | 3 | 6 | 10 | 8 | 27 | 1 |
| 71 | 1 | 2 | 251 FO | 1 | 99 | 99 | 3 | 6 | 10 | 8 | 27 | 1 |
| 71 | 1 | 2 | 251 FO | 1 | 99 | 99 | 3 | 1 | 5 | 3 | 50 | 2 |
| 72 | 1 | 2 | 251 FO | 1 | 99 | 99 | 3 | 7 | 14 | 10 | 23 | 1 |
| 72 | 1 | 2 | 251 FO | 1 | 99 | 99 | 3 | 1 | 5 | 3 | 50 | 2 |
| 2010 | 1 | 1 | 251 FO | 1 | 1 | 1 | 1 | 15 | 20 | 17 | 7 | 1 |
| 2002 | 1 | 1 | 254 FH | 1 | 99 | 99 | 1 | 99 | 99 | 6 | 14 | 1 |
| 4003 | 1 | 1 | 251 FO | 1 | 2 | 5 | 2 | 5 | 99 | 99 | 99 | 1 |

GENERAL OBSERVATIONS

| SITE | MCD | GPG | SOIL | |
|---|---|---|---|---|
| 46 | 1 | 1 | 251 FO | AT I1(?), YIELDS AFTER F2-3 SUBSTIALLY HIGHER THAN CONT CULTN. |
| 48 | 1 | 1 | 251 FO | AT I4, OM POSSIBLY STABILIZED, 50 PCT LOWER, AFTER 5Y CONT CULTN. |
| 63 | 1 | 1 | 251 FO | AT I1, AFTER F1-8, SOIL MICROFAUNA 0.5-0.7 LEVEL UNDER FOREST; AFTER F10-15, 0.7-0.9 LEVEL. |
| 27 | 1 | 2 | 251 FO | AT I1, 3C/3F GAVE STEADY YIELD. CONT CULTN AT 7T/HA/Y FYM. |
| 64 | 1 | 2 | 251 FO | BASES MUCH LOWER UNDER SC THAN NATURAL VEGETATION, C NO SIG.DIFF. |
| 2009 | 1 | 1 | 251 FO | AT I1, EROSION LOSSES, KG/HA/Y: C, FOREST 23, CULTN 200; N, CULTN5, WITH C2/F15, MINERAL SOIL LOST AT 1 CM IN 1300-2400Y. |
| 82 | 1 | 2 | 251 FO | AT I1, YIELDS DECLINED IN C4 AFTER GRASS, NPK AT I3 SUSTAINED YIELDS OF MAIZE, COTTON, SWEET POTATOES BUT NOT OF GROUNDNUTS, FINGER MILLET. K DEFICIECY PROBABLY LIMITING, AND K SUPPLY A MAIN FUNCTION OF GRASS FALLOW. |
| 2010 | 1 | 1 | 251 FO | AT I1, C1/F15, V LARGE EXCH. BASE CYCLIC CHANGE, BUT FOUND NO RELATION BETWEEN C AND STAGE OF REGENERATION; C 3-4 PCT AT ALL STAGES |
| 4003 | 1 | 1 | 251 FO | AT I1, NORMAL PRACTICE C2, F OVER 5. AFTER F5, FOREST LOOKS FAIRLY MATURE BUT C, CA, MG NOT YET RESTORED. |
| 4004 | 1 | 1 | 251 FO | CLEARANCE, BURNING+1Y CULTN CAUSED LOSSES FROM PLANT-SOIL SYSTEM OF (KG/HA) 1300-1400 N, 60-140 K, 100-240 CA, 30-80 MG. CATIONS RESTORED VIA RAIN IN 10-20Y, N BY FIXATION (EST, 100-150/Y) IN 9-14Y. SYSTEM INEFFICIENT, 15-45% ELEMENT LOSSES ON CLEARANCE. |
| 4 | 1 | 2 | 252 FX | AT I4, C5 CAUSED YIELD DECLINE, L3 FAILED TO RESTORE YIELDS BUT I3 DID SO. |

## 2. Extract from "FALSUM"; the summary program

**INPUT LEVEL 1: LOW**

| SITE | LAT | LNG | CONTINENT | TYPE OF EVIDENCE | INPUT LEVEL | ENVIRONMENT MCD | GPG | SOIL | CULTIVATION INTENSITY, R% | WEIGHT | NOTES |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3012 | 25 | 92 | ASIA | QUESTIONNAIRE | 1 | 1 | 1 | 250 F | < 38 | 1.0 | |
| 3017 | 3 | 113 | ASIA | QUESTIONNAIRE | 1 | 1 | 1 | 250 F | < 9 | 0.5 | |
| 3017 | 3 | 113 | ASIA | QUESTIONNAIRE | 1 | 1 | 1 | 250 F | 7 | 1.0 | |
| 12 | 6 | 2 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 1 | 251 FO | >= 17 | 1.0 | |
| 12 | 6 | 2 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 1 | 251 FO | < 29 | 1.0 | |
| 13 | 1 | 24 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 1 | 251 FO | >= 23 | 1.0 | |
| 24 | 6 | -1 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 1 | 251 FO | >= 21 | 1.0 | |
| 32 | 6 | 6 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 1 | 251 FO | >= 22 | 1.0 | |
| 33 | -4 | 20 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 1 | 251 FO | >= 17 | 1.0 | |
| 34 | 9 | -13 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 1 | 251 FO | >= 20 | 1.0 | |
| 71 | 0 | 32 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 2 | 251 FO | >= 27 | 1.0 | |
| 71 | 0 | 32 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 2 | 251 FO | < 50 | 1.0 | |
| 72 | 2 | 32 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 2 | 251 FO | >= 23 | 1.0 | |
| 72 | 2 | 32 | AFRICA | OBSERVED PRACTICES | 1 | 1 | 2 | 251 FO | < 50 | 1.0 | |
| 2010 | -1 | 132 | ASIA | OBSERVED PRACTICES | 1 | 1 | 1 | 251 FO | >= 7 | 1.0 | |
| 4003 | 3 | -65 | AMERICA | OBSERVED PRACTICES | 1 | 1 | 1 | 251 FO | >= 29 | 1.0 | |
| 27 | 0 | 32 | AFRICA | EXPERIMENT | 1 | 1 | 2 | 251 FO | 50 | 1.0 | |
| 46 | 7 | -1 | AFRICA | EXPERIMENT | 1 | 1 | 1 | 251 FO | << 100 | 2.0 | |
| 82 | 1 | 33 | AFRICA | EXPERIMENT | 1 | 1 | 2 | 251 FO | < 100 | 1.0 | |
| 12 | 6 | 2 | AFRICA | NUTRIENT CYCLING | 1 | 1 | 1 | 251 FO | < 55 | 4.0 | LIMIT BY C CYCLE |
| 12 | 6 | 2 | AFRICA | NUTRIENT CYCLING | 1 | 1 | 1 | 251 FO | > 14 | 4.0 | LIMIT BY C CYCLE |
| 4004 | 6 | -74 | AMERICA | NUTRIENT CYCLING | 1 | 1 | 1 | 251 FO | > 9 | 1.0 | |
| 4004 | 6 | -74 | AMERICA | NUTRIENT CYCLING | 1 | 1 | 1 | 251 FO | < 20 | 1.0 | |
| 9999 | 999 | 999 | GENERAL | NUTRIENT CYCLING | 1 | 1 | 1 | 251 FO | < 55 | 2.0 | LIMIT BY N CYCLE |
| 9999 | 999 | 999 | GENERAL | NUTRIENT CYCLING | 1 | 1 | 1 | 251 FO | > 15 | 2.0 | LIMIT BY N CYCLE |
| 9999 | 999 | 999 | GENERAL | NUTRIENT CYCLING | 1 | 1 | 1 | 251 FO | +- 33 | 2.0 | LIMIT BY N CYCLE |
| 1019 | 6 | 4 | AFRICA | QUESTIONNAIRE | 1 | 1 | 1 | 251 FO | < 29 | 0.5 | |
| 1019 | 6 | 4 | AFRICA | QUESTIONNAIRE | 1 | 1 | 1 | 251 FO | 10 | 1.0 | |
| 1049 | 5 | 8 | AFRICA | QUESTIONNAIRE | 1 | 1 | 1 | 251 FO | < 36 | 0.5 | |
| 1049 | 5 | 8 | AFRICA | QUESTIONNAIRE | 1 | 1 | 1 | 251 FO | 30 | 1.0 | |
| 1049 | 5 | 8 | AFRICA | QUESTIONNAIRE | 1 | 1 | 1 | 251 FO | 40 | 0.5 | |
| 4 | 8 | -1 | AFRICA | EXPERIMENT | 1 | 1 | 2 | 252 FX | < 62 | 1.0 | |
| 3018 | -2 | 103 | ASIA | QUESTIONNAIRE | 1 | 1 | 1 | 252 FX | >= 7 | 1.0 | |
| 2002 | -18 | 178 | ASIA | OBSERVED PRACTICES | 1 | 1 | 1 | 254 FH | >= 14 | 1.0 | |
| 6 | 2 | 33 | AFRICA | EXPERIMENT | 1 | 1 | 2 | 254 FH | 60 | 2.0 | |
| 26 | 2 | 33 | AFRICA | EXPERIMENT | 1 | 1 | 2 | 254 FH | 40 | 1.0 | |

Note: Complete printouts of both programs, giving available data on all climates, soil types and input levels, may be obtained on request by writing direct to: Professor A. Young, School of Environmental Sciences, University of East Anglia, Norwich NR4 6TJ, U.K..

# APPENDIX C

## ORIGINAL RESULTS OF THE AFRICA/ASIA STUDY AND THE AMERICA STUDY

Table C.1 CULTIVATION FACTORS, AFRICA/ASIA. INPUT LEVEL 1: LOW

| Major climatic division | Warm tropics | | | Cool tropics | | Warm subtropics | Cool subtropics | Medi-terranean |
|---|---|---|---|---|---|---|---|---|
| Growing period, days | Rain forest zone 270-365 | Savanna zone 120-269 | Semi-arid zone 75-119 | Rain forest zone 270-365 | Savanna zone 120-269 | All | All | All |
| R, Q Regosols and Arenosols | 10 | 15 | 25 | 20 | 25 | 25 | 35 | 35 |
| F Ferralsols | 25 | 25 | (30) | 30 | 35 | 35 | 40 | (50) |
| Fh | 50 | | | | | | | |
| A Acrisols | 25 | 25 | (30) | 30 | 35 | 35 | 40 | (50) |
| Ah | 50 | | | | | | | |
| L Luvisols | 25 | 35 | 50 | 30 | 50 | 50 | 50 | 50 |
| B Cambisols | 35 | 65 | 50 | 45 | 65 | 75 | 80 | 50 |
| N Nitosols Nd | 25 | 30 | (40) | 50 | 75 | 75 | 80 | 50 |
| Ne | (40) | 75 | 75 | | | | | |
| V Vertisols | (40) | 75 | 50 | 50 | 75 | 75 | 80 | 50 |
| J, G Fluvisols and Gleysols | 60 | 90 | 90 | 90 | 90 | 90 | 90 | 90 |

All values refer to the cultivation factor R, expressed as a percent. For definition see Section 2.3.2.

Values in brackets relate to soils unlikely to occur within the climatic region.

Table C.2 CULTIVATION FACTORS, AFRICA/ASIA. INPUT LEVEL 2: INTERMEDIATE

| Major climatic division | Warm tropics | | | Cool tropics | | Warm subtropics | Cool subtropics | Medi-terranean |
|---|---|---|---|---|---|---|---|---|
| Growing period, days | Rain forest zone 270-365 | Savanna zone 120-269 | Semi-arid zone 75-119 | Rain forest zone 270-365 | Savanna zone 120-269 | All | All | All |
| R, Q Regosols and Arenosols | 30 | 40 | 50 | 40 | 50 | 50 | 55 | 45 |
| F Ferralsols | 50 | 50 | (60) | 55 | 60 | 75 | 80 | (70) |
| A Acrisols | 65 | 60 | (60) | 70 | 75 | 90 | 90 | (70) |
| L Luvisols | 65 | 65 | 75 | 70 | 75 | 90 | 90 | 70 |
| B Cambisols | 80 | 70 | 75 | 85 | 85 | 90 | 90 | 70 |
| N Nitosols | 50 | 90 | 75 | 70 | 90 | 90 | 90 | 70 |
| V Vertisols | (65) | 80 | 70 | 70 | 90 | 90 | 90 | 70 |
| J, G Fluvisols and Gleysols | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 |

Table C.3 CULTIVATION FACTORS, AFRICA/ASIA. INPUT LEVEL 3: HIGH

| Major climatic division | Warm tropics | | | Cool tropics | | Warm subtropics | Cool subtropics | Medi-terranean |
|---|---|---|---|---|---|---|---|---|
| Growing period, days | Rain forest zone 270-365 | Savanna zone 120-269 | Semi-arid zone 75-119 | Rain forest zone 270-365 | Savanna zone 120-269 | All | All | All |
| R, Q Regosols and Arenosols | 50 | 65 | 50 | 60 | 75 | 75 | 75 | 50 |
| F Ferralsols | 75 | 75 | (75) | 80 | 80 | 80 | 85 | (90) |
| A Acrisols | 75 | 75 | (75) | 80 | 90 | 80 | 85 | (90) |
| L Luvisols | 80 | 90 | 90 | 85 | 90 | 90 | 90 | 90 |
| B Cambisols | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 |
| N Nitosols | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 |
| V Vertisols | (90) | 90 | 90 | 90 | 90 | 90 | 90 | 90 |
| J, G Fluvisols and Gleysols | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 |

(Tables C.4 to C.6 I leave you to type these from Charles Wright's Report. I suggest his fold-out sheet, with A to Z alphabetically, should go in as it stands, divided into three separate tables for each input level. It would defeat the purpose of this Appendix, to give the results in their original form, if we were to force Charles' results into my format.)