FAO SOILS BULLETIN **43**

organic recycling in africa

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME

CONTENTS

I. INTRODUCTION

In December 1974, FAO organized an Expert Consultation financed by the Swedish International Development Authority (SIDA), on the use of organic materials as fertilizers. The conclusions of this Consultation were published in January 1975 in FAO Soils Bulletin 27 "Organic materials as fertilizers" (FAO 1975).

Attention was drawn in that publication to the lack of interest in agronomic research into the utilization of organic materials as fertilizers. This was attributed to the adequate supply of mineral fertilizers at relatively modest prices before 1973/74. However, since that time, the situation has greatly changed and it was soon realized that the world's raw materials are not unlimited and that their rational use is a prime necessity. This has been even more important in recent times with the rising cost of energy and greater deficit in food production in most developing countries. Policy makers as well as scientists have started to acquire an honest appreciation of the possibilities of reducing the wastage of materials which could be profitably utilized for improving or maintaining soil productivity. In addition, the great opportunities offered by making more efficient use of the potentials of biological nitrogen fixation in farming systems are now fully recognized.

SIDA, through FAO, financed four Regional Workshops in Asia, Africa, the Near East and Latin America primarily to motivate agriculturalists and scientists to take a fresh look at the problems of Organic Recycling in Agriculture and to develop action oriented programmes. The present publication is the proceedings of the second Regional Workshop.

A number of recommendations and suggested guidelines were made by the various Working Groups during the two-week Workshop. These covered:

1. Cropping systems and crop residue management.
2. Biological N-fixation.
3. Research, training and extension.

A central theme much emphasized at the Workshop was the fact that agricultural policy makers, technicians and scientists need to study more closely the basic practices of the small farmers so that proposals for the introduction of new systems could be easily understood, integrated and accepted by these farmers.

This publication, it is hoped, will serve as a valuable source of information and guideline for teachers, researchers, extension officers and agricultural policy makers in Africa. Above all, it also throws light on some of the areas where valuable cooperation among developing countries could be achieved through such programmes as "Technical Cooperation among Developing Countries" (TCDC).

THE OPENING SESSION

The FAO/SIDA Workshop on Organic Recycling in Agriculture in Africa was held in Buea, from 5-14 December 1977, through the courtesy of the Government of the United Republic of Cameroon. 1/

In his opening address, Mr. Ly, FAO Country Representative in Cameroon, on behalf of the Director-General of FAO, welcomed the participants from the various countries and drew their attention to the importance of the Workshop particularly at a time when costs of agricultural inputs such as fertilizers, pesticides, herbicides, etc., have increased at such a staggering rate that most of the countries in Africa find it a heavy burden on

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1/ For full text of speeches, please see Appendix 3.

their budget. It is at this stage that every attention should be directed to finding the cheapest but most efficient ways to recycle organic residues in agriculture and to make use of crop rotations to increase and maintain soil productivity. He paid a special tribute to the Government of the United Republic of Cameroon for hosting the Workshop and to SIDA for the financial support.

Fon Fosi Yakum-Ntaw, Governor of the South West Province, welcomed the participants on behalf of the Government. He stressed the importance the Government of the United Republic of Cameroon attached to the Workshop being attended by over 40 agriculturalists, scientists and technicians from 16 African countries in the Region. The Governor made a special plea to the participants to devote their time during the Workshop to the understanding of the problems facing the small farmers, find solutions and develop the appropriate strategy to implement measures which will help them to increase food production. He advised that the fight against underdevelopment is long and exacting but necessary and urgent. Above all, he hoped that the participants would not fail to realize that agriculture is still and will remain for a long time the main economic activity in most of Africa.

NOTE

In this report, authors of papers had used either the elemental or oxide forms for phosphorus, potassium, etc., but these have been changed to the elemental. For the ease of readers the conversion factors used were:

$P_2O_5 \times 0.4364 = P$ $\quad$ $P \times 2.2919 = P_2O_5$

$K_2O \times 0.8302 = K$ $\quad$ $K \times 1.2046 = K_2O$

$CaO \times 0.7147 = Ca$ $\quad$ $Ca \times 1.3992 = CaO$

$MgO \times 0.6030 = Mg$ $\quad$ $Mg \times 1.6582 = MgO$

II. SUMMARY OF DISCUSSION GROUPS AND RECOMMENDATIONS

1. WORKING GROUP ON CROPPING SYSTEMS AND CROP RESIDUE MANAGEMENT

1.1 Introduction

For purposes of this discussion the arable lands of tropical and sub-tropical Africa have been split up into three ecological zones:

1. Humid tropical zone
2. Savannah zone
3. Semi-arid zone

For each zone, the main cropping systems practised and the methods of crop residue management have been examined. In addition, mixed farming as currently practised has been reviewed to examine the usefulness of the crop residue produced as a source of farmyard manure.

1.2 Ecological Zones

1.2.1 Humid Tropics

i. Cropping systems

- Perennial monoculture : as practised in plantation agriculture
- Banana/plantain shade + perennials as practised in the establishment of cocoa farms.
- Perennials + annuals e.g. coffee + maize + vegetables + legumes.
- Annuals + perennials (emphasis here is on the cropping sequence).
- Root + tuber crops + cereals + vegetables

ii. Crop residue management practices

In the Humid tropics there is rapid production of large quantities of crop residues as a result of favourable climatic factors. These same factors favour rapid decomposition of organic materials.

Some of the residues produced are utilized as mulch in plantations. Apart from this use, there is no systematic way of managing crop residues especially with food crops. Some residues are burnt.

1.2.2 Savanna

i. Cropping systems

- Perennial monoculture e.g. coffee,tea, sugarcane (montane or irrigated).
- Sole crop : cereals e.g. maize, upland rice.

- Sole crop (others) groundnuts, sesame, cotton, soybean, phaseolus.
- Cereals + legumes.
- Cereals + root and tuber crops.
- Cereals + cotton
- Root and tuber crops + cereals + vegetables + legumes (montane savanna variant).

ii. Crop residue management practices

More crop residues are generated in this zone than in the humid tropics. The problem here is to maintain an adequate organic matter turnover rate.

On sugarcane plantations (East Africa) the crop is burnt, tops cut off and left on the ground. The bagasse from the factory is burnt as fuel rather than returned to the field.

For the other perennials, the residues are used as mulch.

For annuals, incorporation of crop residues into the soil takes second place to a multitude of other uses, e.g. cereal residues are used for fencing, fuel, matting and thatch. Legume haulms are fed to small livestock such as sheep. Burning of residues and fields is a common practice especially by graziers.

1.2.3 Semi-Arid Zone

i. Cropping systems

- Rotational cropping involving fallow, millet, groundnuts especially in Senegal.
- Dry season sorghum (muskwari) especially in the black clay soils around Lake Chad.
- Cereals + legumes

ii. Crop residue management practices

Similar to the practices in the savanna with respect to annual crops.

1.3 Recommendations

1.3.1 Short-term recommendations

i. The practice of mulching on perennials should be encouraged and intensified.

ii. In the humid zone where residue degradation is fast, crop residues should be spread over the field to rot. This will assist in controlling weeds and facilitate the practice of minimum tillage.

iii. Proper preparation and conservation of compost, especially of household refuse and some vegetative matter should be encouraged. This would involve the training of farmers.

iv. Organic matter is no substitute for mineral fertilizers. They should complement each other and where crop residues with high C/N ratios are applied, efforts must be made to include mineral nitrogen fertilizers.

v. Rotational farming, including fallows where praticable, should be encouraged especially in the savanna and semi-arid zones where maintenance of the organic matter status of the soils is very critical.

vi. The practice of burning either crop residues or farm land fallows causes rapid soil degradation and should be discouraged.

1.3.2 Long-term recommendations

With the long-term objective of optimum utilization of crop residues for soil fertility maintenance in view, the desirability of evolving systems which will integrate the production of crops with the raising of animals is foreseen.

In this respect it is pertinent to review mixed farming as currently practised in various parts of Africa.

i. Mixed farming practices

In the case of East and Central Africa animals are kraaled on communal land away from farm land during the growing season. In low population density areas little effort is made to return the dung produced to the crop lands. Under high population pressure however, the dung is transported and spread on cropped land.

During the dry season the animals graze at large on all the cropped lands.

In some areas animals are kraaled on a piece of land which is subsequently cropped, utilizing the dung which had been deposited on the land.

Small animals such as sheep, goats, pigs, poultry etc. are often raised around homesteads. No systematic manure collection is done but droppings may be utilized in gardens around the homestead.

Except for a few instances, there is little integration between crop farming and animal production. The crop farmer recognizes the benefit of dung as evidenced from the practice in East Africa where he purchases dung from cattle rearers and in Northern Nigeria where a Hausa farmer contracts with the Fulani herdsman for the latter's animals to graze on his land.

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2. WORKING GROUP ON NITROGEN FIXATION

2.1 Introduction

The role of biological fixation in various cropping systems in the African region, such as monocropping, intercropping, mixed cropping, cover cropping, as well as in crop residue management systems was stressed. Although recognized, the need to stress this role was not matched to any extent in almost all the developing African states by efforts to utilize and promote its contribution at farm level to raising crop yields and quality of legumes.

The energy crisis no doubt prompted the adoption of a more positive attitude in the formulation of a strategy for increasing food production at farm level through the better use of legume inoculation. Efforts by the international centres, IITA and IRRI, in Africa and Asia respectively, and the current FAO/UNEP activity aiming at the "Development of a Co-ordinated Programme of Biological Nitrogen Fixation" (mainly symbiotic) are noted and well appreciated. Benefits which are likely to accrue from nitrogen fixation are:

i. savings on expensive imported N fertilizer,

ii. increased yield of legumes,

iii. well maintained soil fertility,

iv. reduced environmental hazards.

The reasons for slow adoption by most African countries of legume inoculation technology already in wide use in developed countries are:

a. shortage of trained soil microbiologists with special interest in Rhizobia in many African countries. This situation has led to an absence of locally produced inoculants and the easy resort to imported material which is both costly and risks being ineffective;

b. lack of funds available for training and equipment;

c. lack of appreciation of the magnitude of the contribution of legume symbiosis.

In the light of the above it seems logical to state the needs for promoting a biological nitrogen fixation programme in Africa.

2.2 Research needs

Legume inoculation should not be considered in isolation but as part of a multidisciplinary approach demanding, besides soil microbiologists, the involvement of soil fertility experts, breeders, agronomists and economists.

2.2.1 Immediate research

i. Determination of the need for inoculation in various soils and climatic conditions.

ii. A programme of isolation, testing and culture collection. This should be actively pursued and a good culture collection of useful Rhizobia maintained.

iii. Assessment of the magnitude of biological nitrogen fixation.

iv. Assessment of the limiting factors (P, Ca, pH, Mo, S, physical conditions, management).

v. Production of legume inoculants.

2.2.2 Medium and long-term

i. Persistence of inoculant strains and infectivity.

ii. Seed dressing - Rhizobia interaction and possibility of developing adapted strains.

iii. Selection of host-strain combination for adverse soil conditions such as drought resistance and salt tolerance.

iv. Inoculation methods to be developed to suit the different farming systems.

v. Assessment of the role of wild legumes in regeneration of soil fertility in fallows.

vi. Other systems of biological nitrogen fixation both symbiotic and non-symbiotic to be investigated, e.g. Azolla, blue-green algae, etc.

2.3 Training and Extension

2.3.1 Immediate

i. Post graduate scientific training for candidates expected to lead the work in national and regional laboratories. This covers short term training as well as that leading to a higher degree.

ii. Applied short-term training courses for agronomists and extensionists involved in national programmes in the field.

2.3.2 Medium and long-term

i. Graduate training: formal university courses in soil microbiology should be strengthened.

ii. Training of legume inoculant manufacturers and quality controllers.

2.4 Recommendations

2.4.1 To governments

i. Governments are urged to develop their national capability in the field of legume inoculation by adopting a favourable attitude towards training and education.

ii. Seek bilateral assistance and help allocate funds for provision of facilities.

iii. Expedite actions to facilitate implementation of technical assistance programmes.

iv. Encourage co-operative programmes with neighbouring countries.

2.4.2 To FAO and other international technical assistance programmes

i. Train nationals at the various levels required. FAO should make available at least four scholarships for post graduate training in legumes and full advantage should be made of training programmes already available in the region in MIRCEN, Nairobi and IITA, Ibadan.

ii. Provide help to initiate trials and demonstrations for legume inoculation in the field where possible.

iii. Strengthen the existing soil microbiology in laboratories and centres by personnel, equipment, transport etc.

iv. Organize seminars, workshops, conferences and training courses within the African region.

v. Create a co-ordination machinery for the region.

vi. Consider the creation of a microbiological centre to serve the dry savannah areas of Africa.

3. WORKING GROUP ON RESEARCH, TRAINING AND EXTENSION

3.1 Introduction

The amounts of organic material available for recycling in the Africa region, and which are presently being wasted due to inappropriate recognition of their great technical, agronomic and economic benefits, are considered to be worth US$5 - 8000 million annually, relative to N, P and K fertilizers. Inadequate utilization of these valuable organic materials resource has been due to:

i. inadequate research on collection, storage, processing, transportation, utilization, and related economics;

ii. lack of sufficient and well-trained personnel to deal with the specific needs of organic material recyling; and

iii. lack of extension programmes deliberately directed at organic recycling, coupled with the supporting infrastructure.

3.2 Research Needs

In order to evolve the appropriate packages of practices to be used in national training and extension programmes both short and long-term inter-disciplinary research will be required.

3.2.1 Short-term

The focus of short-term research will be to evolve the techniques and processes most appropriate for annual extension programmes. The important areas are:

i. Economics of the use of appropriate combinations of organic and inorganic fertilizer materials, in relation to production and soil productivity.

ii. Survey of the nutrient composition of various organic materials used in agricultural production.

iii. Survey of the contribution of legumes to the productivity of different farming systems.

iv. Development of efficient and rapid methods of producing composts from different organic materials.

v. Development of techniques for the safe handling, storage and application of rural, urban and industrial wastes in agriculture.

vi. Study of existing biogas projects in various countries with a view to developing suitable plants utilizing local materials and technology.

vii. Assessment of the socio-economic and environmental implications of recommendations from research findings.

3.2.2 Long-term

Long-term research is needed on the following subjects:

i. Long-term effects of organic and inorganic materials, singly or in combinations, on the physical and chemical properties of soils and soil productivity.

ii. Assessment of indigenous and exotic legumes for their nitrogen fixing efficiencies, food or fodder production, and effects on soil productivity and conservation.

iii. Survey of organic, industrial and other waste products, such as Neem or Melia (Azadirachta) for their potential use as bases for slow release N-fertilizers and for their other agriculture uses.

iv. Effect of continuous application of different organic materials on soil properties and productivity.

v. The possibilities of finding mixed farming systems which would be best suited to each ecological zone in the Africa region.

vi. The development of suitable equipment or plants for the processing, storage and transportation of organic materials.

vii. Methods of recycling organic materials through animals and micro-organisms (mushrooms).

viii. Evolving methods suitable for the incorporation of organic and inorganic fertilizer materials under mixed or multiple cropping systems.

ix. Monitoring the fertility status of soils receiving organic material amendments with a view to the development of suitable soil testing programmes.

x. Finding quick-growing trees and shrubs for establishment in dry areas, both to reduce desert encroachment and to cut down the usage of existing plant species as fuel, and for other agricultural purposes.

xi. Increased support to national and international research institutions and universities for the conduct of scientific and technological studies geared to the development of organic materials in agriculture and biological N-fixation.

xii. The role Azolla might play in agricultural production in the tropics.

3.3 Extension and Training

In order to provide for increased productivity from the land through the utilization of organic materials, well organized manpower development and extension programmes, are essential.

3.3.1 Manpower development

i. Intensify the training of technical and professional cadres in the use of organic materials.

ii. Provide both theory and practical training in the principles, collection, processing, storage, transportation and utilization of organic materials, to primary and secondary schools, colleges, institutes and universities, and the farming community.

iii. Train liaison officers and subject-matter specialists in organic material recycling, at regional and national levels, to spearhead programmes and to serve as competent trainers of other staff and farmers.

iv. Train and provide adequate/well-trained manpower for Rhizobium work.

v. Train technical and professional personnel in research methodology in soil fertility evaluation and management in the field of organic materials and biological nitrogen fixation.

3.3.2 Extension

i. Organization of seminars and short training courses of an in-service nature at local, national and international levels on important issues on organic materials.

ii. Development of suitable national programmes for the promotion of better utilization of organic materials in agriculture, these being integrated with on-going programmes.

iii. Production of appropriate literature, practical manuals and audio-visual aids to help extension and staff training programmes.

iv. Involve extension staff in the planning of research projects directed at solving specific extension projects, ensuring that socio-economic consideration are included.

v. Make available research findings and publications on the use of organic materials in agriculture, or lists thereof, for the use of other workers, trainers, trainees and farmers.

vi. Seek, or offer fellowships on the utilization of organic materials in agriculture, tenable both within and outside the national countries; and award, in various ways, those who have done meritorious work in the field of organic material recycling and biological nitrogen fixation.

vii. Encourage member countries of FAO to organize similar workshops on recycling and biological nitrogen fixation.

viii. FAO is recommended to work out suitable guidelines to be used for the building up of national programmes in organic recycling and biological nitrogen fixation, in relation to the country needs; in this respect FAO to be ready to offer consultants to assist national governments with such planning where this is requested.

ix. Appointment of an expert to co-ordinate activities in organic material recycling and biological nitrogen fixation at the national level, which expert may be requested from FAO, also provide a national expert, or an FAO-appointed expert to produce extension and training materials on a consultant or other basis.

III. TECHNICAL PAPERS

Paper 1

A REVIEW OF CROPPING SYSTEMS IN RELATION TO RESIDUE MANAGEMENT IN THE HUMID TROPICS OF AFRICA

B.N. Okigbo [1]

Summary

The nutrient cycling processes in various farming systems reviewed here are more or less superficial, because quantitative data are not easy to come by for all of them. Figure 3 illustrates comparatively the flow chart components of the processes involved. It gives only a rough idea of the nutrient cycles but it is reasonably sufficient for designing practices for efficient nutrient conservation and utilization. It is hoped that in future as results of ongoing studies become available and studies of farming systems of tropical Africa intensified, it will be possible to determine quantitatively the nutrient pathways involved in each farming system.

1. ENVIRONMENTAL SETTING

The humid tropics of the world is a belt of varying width that destrides the equator mainly between 7° north and south of the equator except on the windward slopes of tropical coasts where it extends up to 15° north or south of it. This is a zone of tropical rainy climates of the Af and Am types of Koppen and Thornthwaite (Trewartha 1968; Hare 1973). It is a belt of high insolation and uniformly high temperatures with annual means from 25 - 27°C in areas near the equator where altitude is not more than 1 000 m. Average temperatures for the coldest months usually exceed 18°C. The region is noted for its high atmospheric humidities and heavy rainfall during all or most months of the year varying from areas of one peak rainfall where the annual rainfall may be up to 4 000 mm with Af climate and no dry season to as low as below 1 500 mm in areas of Am climate with two peaks of rainfall and a distinct dry season (Figure 1). The Af climate supports a climax vegetation of tropical rainforest of mainly broad leaved evergreens whereas the Am areas support mixtures of evergreens and deciduous trees with dormant periods of leaf fall. As a result of human activities including farming, grazing, clearing, slashing and burning, virgin forests are rare in the northern margins of West Africa and the rainforest has been reduced to a 'Derived Savanna' vegetation.

Soils of the humid tropics consist mainly of oxisols, alfisols and ultisols (Donahue 1970; Sanchez 1976). As compared to the soils of the temperate regions they are characterized by (a) deeper and more intensely weathered pedons with few remaining weatherable minerals, (b) lower percentage of silicon, (c) higher percentage of iron and aluminium, especially in the form of amorphous oxides, (d) higher percentage of kaolinite and smaller percentage of montmorillonite, (e) lower cation exchange capacity, (f) lower buffer capacity, (g) lower available water capacity, (h) a lateritic (plinthite) layer in some soils that harden by crystallization of the iron on continuous exposure to cycles of wetting and drying as would occur under continuous cropping, (i) less accumulation of leaf litter as a result of more rapid decomposition and (j) low reserves of total available nutrients (Donahue 1970). Consequently, although these soils possess good structural characteristics, they are inherently infertile and processes of degradation are intense and active throughout the year. Fertility is maintained in the surface horizons under forest or good vegetation cover but rapid loss in fertility and soil erosion occur with the removal of vegetation, especially on sloping land.

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[1] International Institute of Tropical Agriculture, Ibadan, Nigeria

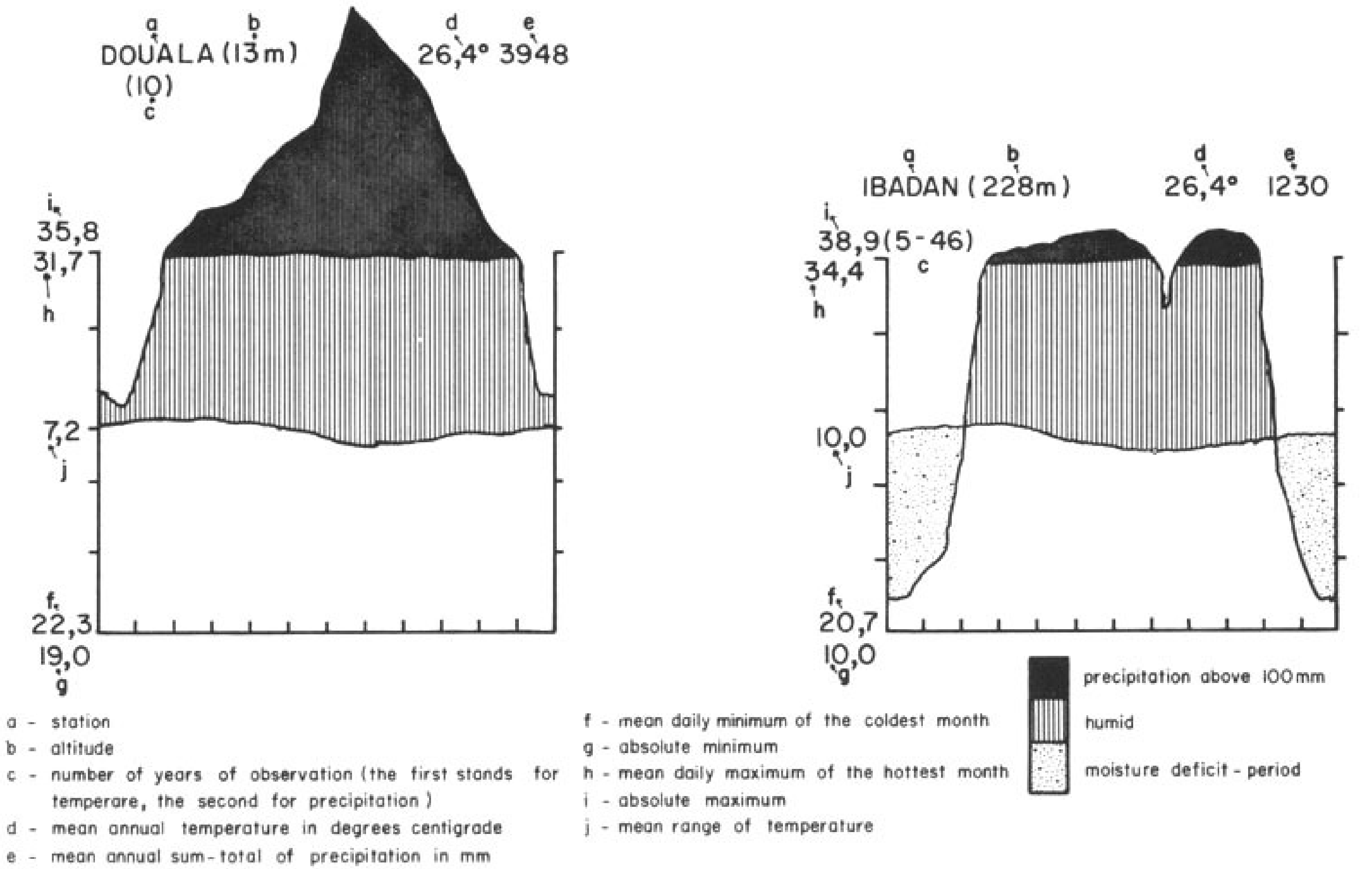

Fig 1. Comparison of climate and vegetation types in two humid and subhumid tropical regions (1) unimodal tropical rainforest (2) bimodal seasonal monsoon forest with some deciduous elements in top canopy (Golley & Leith, 1972)

The most widespread farming sytems of the humid tropics consist of bush fallow systems of varying periods of fallow and degrees of permanency, not much of plantation agriculture, limited livestock production and negligible use of mineral fertilizers for the maintenance of soil fertility. It is against this background that the importance of mineral recycling and residue management in cropping systems of the humid tropics is considered below.

2. IMPORTANCE OF CROPPING SYSTEMS IN FARMING SYSTEMS OF THE HUMID TROPICS OF AFRICA

While there is evidence that agriculture as man's oldest occupation slowly evolved 11 000 years ago, there is general agreement that it's nature and time of origin varied from place to place. Moreover, it also varies from one location to another in relation to climate, soils, vegetation, animals, level of technology achieved or now in use and the prevailing overall socio-economic environment. Consequently, attempts have been made to classify agricultural or farming systems and other related activities. Whittlesey (1936) on the basis of (1) crop and livestock association, (2) methods used to grow the crop and produce stock, (3) intensity of use of labour, capital and other resources, (4) method of disposal of products for consumption and (5) the ensemble of structures used to house and facilitate farming operations recognized thirteen major types of farming. In tropical Africa, Porteres (1962) reported that originally there were developed two agricultural complexes, a seed agricultural complex characteristic of the savannah in fields and a vegecultural complex peculiar to the rain forest and involving cultivation of roots, tubers and cuttings in gardens. But as a result of changes which these farming systems have undergone with time and especially those due to interaction of peoples, crops, animals and techniques from elsewhere with local resources, differences between the two complexes have tended to disappear. Studies of farming systems of tropical Africa and other developing countries by Allan (1965), Miracle (1967), Morgan (1959 and 1969), Morgan and Pugh (1959), Floyd (1969), Boserup (1970), Benneh (1972) and Greenland (1974), have resulted in the classification of the various farming systems of tropical Africa on the basis of differences in intensity of cropping or cultivation and variations in the duration of fallow used for restoration of soil fertility by nutrient recycling after each cropping phase. These are presented in Table 1 and include traditional farming systems, their modifications or transitional farming systems and local adaptations of systems developed in Europe, North America or Asia.

Table 1

GENERAL CLASSIFICATION OF FARMING SYTEMS
FOUND IN WEST AFRICA [1]

A. Traditional and Transitional Farming Systems.

1. Shifting cultivation (Phase 1 including nomadic herding) $L > 10$ [2]
2. Bush Fallowing or Land Rotation (Shifting Cultivation Phase II) L5-7
3. Rudimentary Sedentary Agriculture (Shifting Cultivation Phase III) L3-5
4. Compound Farming and Intensive Subsistence Agriculture (Shifting Cultivation Phase IV) $L < 2$
5. Terrace Farming and Floodland Agriculture $L < 1$

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[1] Adapted with modifications from Greenland 1973; Floyd 1969; Morgan and Pugh 1969; Whittlesey 1936; and Laut 1971).

[2] L = Land use Factor of Allan (Greenland 1973) = $\frac{C+F}{C}$ where C = Cropping period in years and F = fallow period in years.

B. Modern Farming Systems and Their Local Adaptations

1. Mixed Farming
2. Livestock ranching
3. Intensive Livestock Production (Poultry, Pig Production and Dairying)
4. Large-scale Plantations
    (a) Large-scale food and Arable Crop Farms
    (b) Irrigation Projects
    (c) Large-scale Tree Crop Plantations
5. Specialized Horticulture
    (a) Fruit Trees and/or ornamentals
    (b) Market gardening

Not all the farming sytems listed in Table 1 exist everywhere in the humid tropics and a majority of them are more complex than the modern farming systems of Europe or North America due to lack of specialization. According to Okigbo and Greenland (1976) their complexity can be illustrated by the fact that in humid tropical areas of Africa a farmer or farm family operates a very much diversified agricultural enterprise which may consist of a combination of different farming or cropping systems. For example, a farmer whose homestead is located in an upland well drained soil may operate a compound farm close to his homestead, while at the same time maintaining two or more plots under cropping systems of different periods of forest, bush or planted fallows at varying distances from his home, and in the flood plains of a nearby river or stream practice floodland cultivation. He may also be keeping goats, sheep and/or poultry for meat, manure and other purposes. The crop mixtures on compound farms and various field types often involve major staples, vegetables and condiment plants grown in multiple, double, relay and patch intercropping patterns of annuals, perennials or both. The compound farm or homestead garden usually carries more species of cultivated plants than bush fallow farms located at various distances from the homestead since on the latter only major staples and a few protected trees may be grown (see Table 2).

The importance of cropping systems as major components of the farming systems in the humid tropics of Africa stems from the fact that with the exception of nomadic herding, and livestock ranching all the farming systems listed involve systematized production of crops. Even where the farming system is based on animals, the animals depend on plants in the form of range forbes, pastures, browse plants and feeds manufactured mainly from plant products for their food.

Table 2

OBSERVATION ON FOOD CROPS AND OTHER USEFUL PLANTS FOUND IN CROP MIXTURES IN COMPOUND AND OUTLYING FARMS IN PARTS OF SOUTHERN NIGERIA

Plant group	Area of Sample										Mean Percentage Frequency
	A 0.003–045 ha		B 0.04 ha		C 0.04–0.4 ha		D 0.04–0.5 ha		E 0.04–0.5 ha		
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	
1. Roots & Tubers	1–12	5	6–6	5	5–8	7	1–8	4	7–9	8	47
2. Cereals & other Starchy staples	0–3	1	1–2	1	2–3	2	0–4	2	2–3	2	38
3. Leaf Vegetables	3–7	4	0–4	2	4–8	6	10–11	6	2–8	5	27
4. Fruit Vegetables	4–6	4	1–3	2	5–6	5	0–6	2	3	3	44
5. Legumes	1–5	3	0–4	2	2–4	2	0–3	1	0–3	2	33
6. Fruits, Nuts & Oil Plants	1–14	5	0–1	1	10–11	10	2–15	7	5–12	9	20
7. Spices & Beverages	0–3	1	0–1	1	2–6	4	0–9	4	1–7	4	18
8. Miscellaneous	0–7	2	0–1	0	10–14	13	1–29	11	4–18	12	11
Range in total number of species or cultivars	6–25		4–19		40–48		6–62		25–52		

A = Transition Zone – Derived Savanna/Oil Palm Bush
B = Transition Zone – Derived Savanna/Oil Palm Bush
C = Oil Palm Bush – High Population Density including very elaborate compound farm system
D = Oil Palm Bush – Medium/High Population Density
E = Oil Palm Bush – High Population Density

3. NUTRIENT RECYCLING AND SOURCES FOR FERTILITY MAINTENANCE AND FOR CROP PRODUCTION IN BUSH FALLOW SYSTEMS

The characteristics, dynamic processes and equilibrium of forest ecosystems of the humid tropics and changes and processes taking place during fallow periods when land is not under cultivation have been reviewed by Nye and Greenland (1960), Hawkins and Brunt (1965), Moss (1969), Grigg (1970), Mouttapa (1974) and Unesco (1975). The climax vegetation in a tropical rainforest or bush fallow of more than 5 years duration usually consists of a multistoreyed structure of evergreens or mixture of evergreens and deciduous trees and shrubs, climbers and herbs. The intensity of growth, complexity and height attained depend on the number of years of development and extent of human misuse or abuse. Hawkins and Brunt (1965) described the structure of the rainforest vegetation at Bamenda in West Cameroun as consisting of 5 strata with the highest layer A made up of plants about 30 - 60 m high of mainly scattered emergent trees, a second B layer of 20 - 30 m trees of 60 % open canopy, a lower C stratum of 10 - 20 m high shorter trees of discontinuous canopy, below which there is a D layer of 3 - 4 m shrubs and tall herbs with the lowest E layer of 0 - 1 m herbs and seedlings. A forest of this kind is a biologically stable ecosystem in dynamic equilibrium in which growth is maintained in a closed cycle of nutrients (Figure 2).

Whenever the forest is cleared and cropped in the practice in traditional bush fallow systems and then left to re-establish itself after two to three years of cropping, Nye and Greenland (1960) found that it usually re-established rapidly in 5- 10 years of fallow. A secondary succession is developed with certain characteristic species being dominant at different stages. It is necessary to consider the nutrient paths in such systems and changes they undergo under various farming practices as a basis for discussion of consequences of residue management in different cropping systems in the humid tropics of Africa.

The amount of wood which accumulates in 4 - 9 years of fallow may exceed 90 - 200 m^3/ha (Nye and Greenland, 1960). This depends on the dominant plant species involved, their rates of growth and development. The amount of dry wood added each year may amount to up to 11 t/ha per annum. Moss (1969) reported that up to 20 species of trees and shrubs and over 30 species of climbers and herbs with different depths and patterns of rooting may occur in sample areas of such forests in humid tropical areas of West Africa. Similar data for tropical America and Asia have been reported by Holdridge et al (1971). These characteristics determine the extent and kinds of nutrient transformations taking place in the soil/plant system.

3.1 Nutrient Cycle

Under forest cover there is a dynamic flow of energy and materials in and out of the system (Figure 2). Some of these materials consist of some of the nutrients required by plants for growth and development. Two main processes are involved in their movement in and out of the system - (a) uptake from the soil and atmosphere by vegetation and (2) removal from vegetation and return to the soil as litter, rain wash, burning and root excretion (Fig. 3). The actual amounts of nutrients involved in each process may be considerable and depends on the nature of the vegetation, the soil and climate, and number of years of growth (Tables 3, 4 and 5). According to Nye and Greenland (1960), the annual turnover in nutrients on the basis of percentage total capital stored in vegetation in a 40-year old mixed secondary bush at Kade in Ghana amount to N 11%; P 11%; K 32%; C 12% and Mg 18%. As a result of this and other observations they made, it was concluded that (1) the subsoil contributes substantially to nutrients taken by plants through their roots, (2) rain wash from leaves mak gnificant contribution of nutrients to the soil, (3) accumulation of nutrients is highest during the first five years following re-establishment

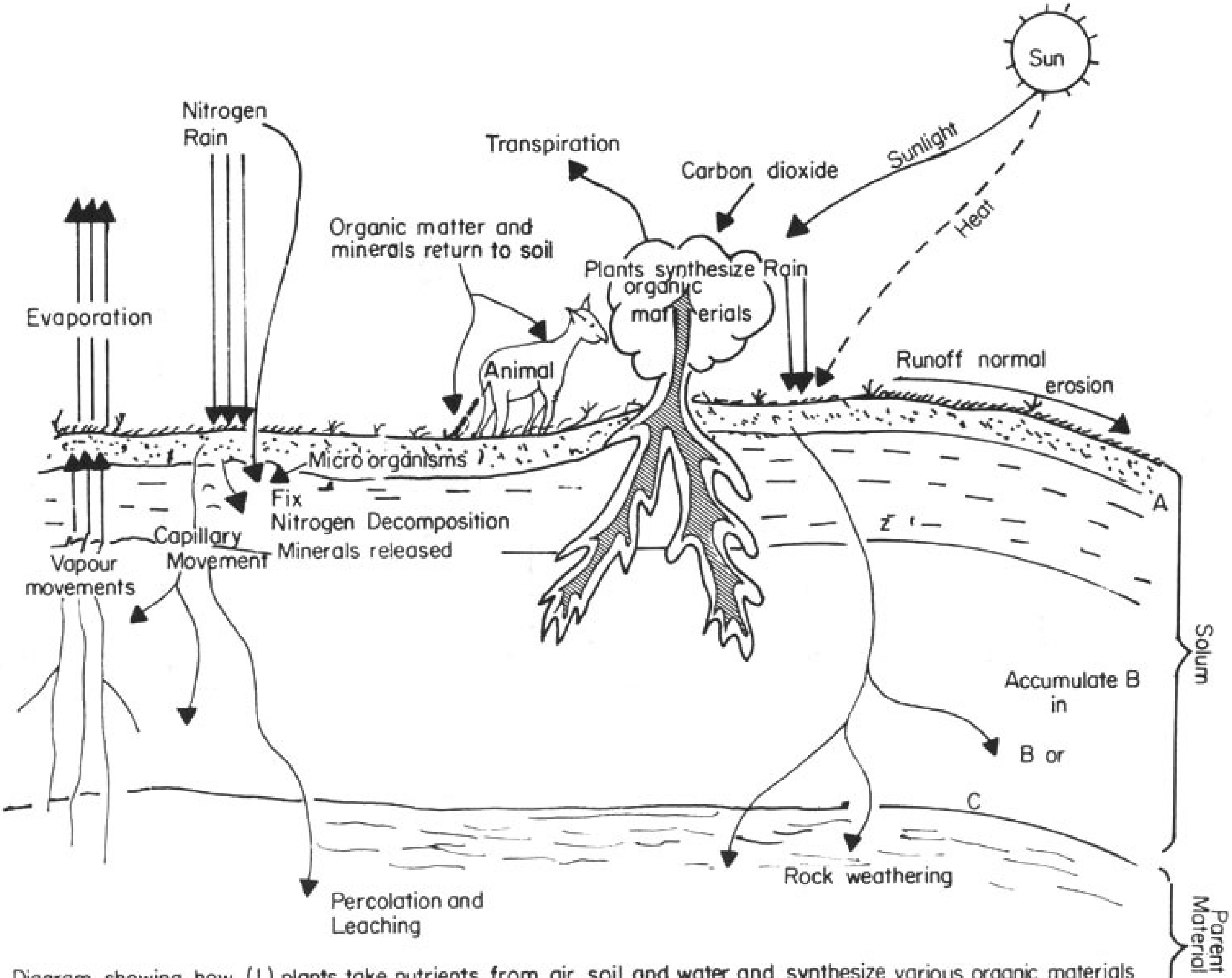

Fig. 2 Diagram showing how (1) plants take nutrients from air, soil and water and synthesize various organic materials (including plant and animal food) under the power of sunlight in the green parts of the plant and (2) how water is taken up and down the soil, through the plant, and off the surface.
(Adapted from Kellog, 1975)

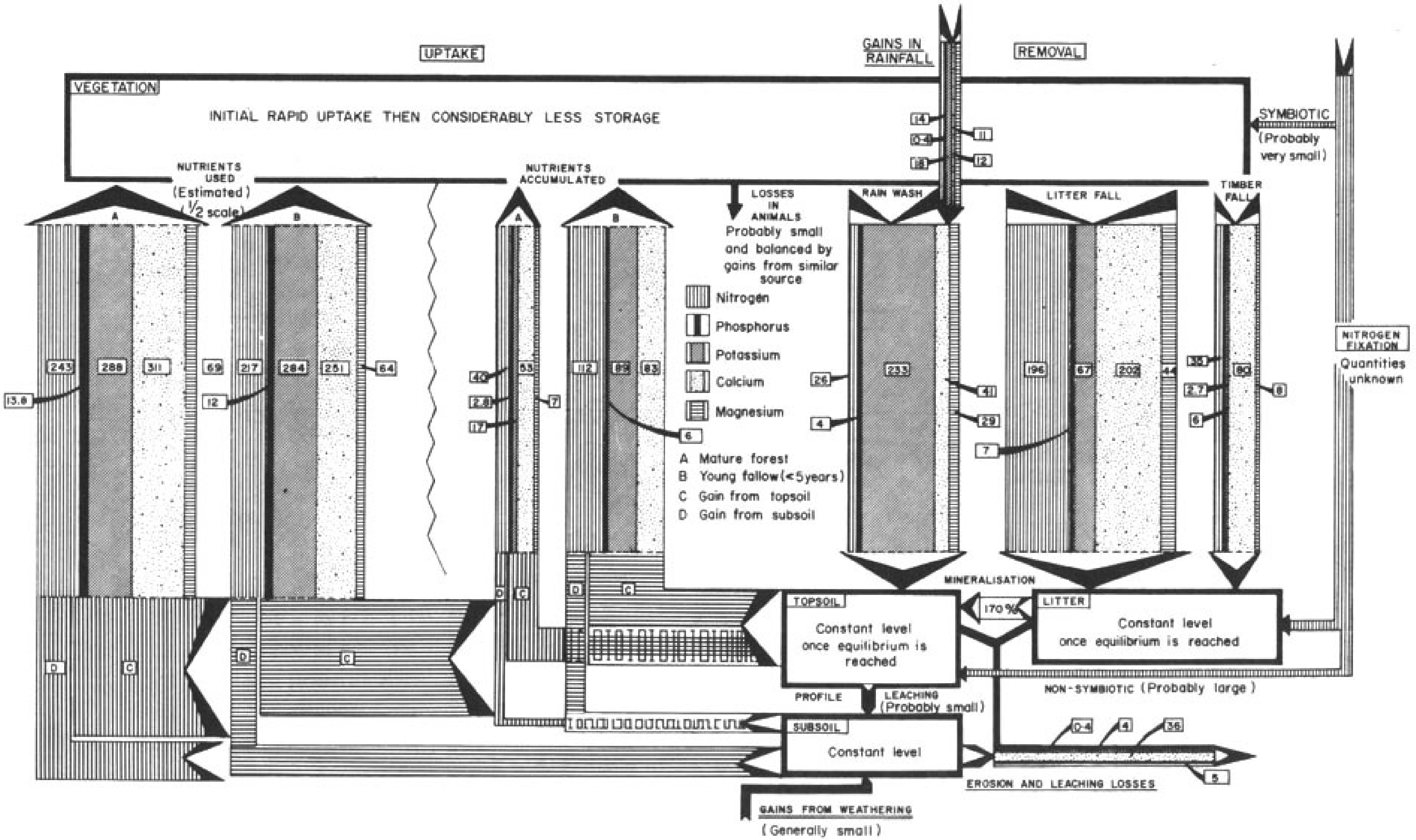

Fig. 3 The nutrient cycle under forest in West Africa (after Nye and Greenland, 1969, Moss, 1969) in kg/ha

Table 3

MEAN ANNUAL INCREASE IN VEGETATION STORAGE (kg/ha)

	N	P	K	Ca	Mg	Forest
Over first 5 years	116	6.3	90	85		Yangambi
Over first 18 years	39	6.0	34	46		Yangambi
Over first 40 years 1/	40	2.8	17	55	7	Kade
	47		35	46	10	Coastal thicket, Pokoase (Nye 1958)
Over first 4 years (excluding roots)						

1/ Storage in two very large trees, already standing when the forest regenerated, has been excluded.
Source: Nye and Greenland (1960)

Table 4

RATE OF LITTER PRODUCTION (PER ANNUM)

Vegetation	Place	Litter Fall (kg/ha)	Nutrients in litter (kg/ha) N	P	K	Ca	Mg	Authority
Forest (Musanga dominant)	Congo	14 800 (dry matter)	139	4.6	103	127	38	Laudelout (1954)
Mixed Forest	"	12 500 (dry matter)	228	6.8	48	105	46	" "
Mixed High Forest	Ghana	10 720 (oven dry)	203	7.3	64	205	40	Nye (Unpublished)
Rain Forest	Colombia	10 500 (oven dry)						Jenny (1950)
" "	"	10 600 (oven dry)						" "
" "(Sub-tropical mixed spp.)	Queensland	6 800 (oven dry-leaf only)	107	6.8	34	75		Webb (1956)
Temperate	New York	3 100 (dry matter)	18	3.3	15	74		Chandler (1941)

Source: Nye and Greenland (1960)

Table 5

NUTRIENT CYCLE IN HIGH FOREST AT KADE, GHANA 1/

	Weight of material (oven dry)	Nutrient Elements (kg/ha/annum) N	P	K	Ca	Mg
Rainfall in open-(1854 mm in 12 months)		15	0.0	18	13	13
Rainfall under forest-(1575 mm in same period		27	4.1	242	39	30
Rain wash from leaves		13	5.0	223	30	18
Timber fall	11 400	35	3.0	6	84	8
Litter fall -(on 12 months' records)	10 720	198	7.3	70	204	54
Total addition to soil surface		252	14.0	287	320	73

1/ Source: Nye and Greenland (1960)

of fallow, and (4) considerable amounts of nutrients are held in the wood and are released when the bush or forest trash is burnt. Rapid mineralization of organic matter occurs at an annual rate that may amount to 170% of the weight of litter at the surface. At temperatures of 20 - 25°C under the forest, humus formation is in equilibrium with mineralization which releases nitrogen and other nutrients.

In the nutrient cycle, gains occur through rainfall, ashes during burning and from the sea in addition to nitrogen fixation by micro-organisms. Losses occur through leaching, erosion removal through runoff and volatilization of nitrogen and organic sulphur through oxidation during burning (Nye and Greenland 1960 and Moss 1969). It is obvious from these changes that under permanent forest cover there is a closed cycle of organic matter and nutrients resulting in an equilibrium in which losses more or less counterbalance gains and normal growth and development occurs. According to Nye and Greenland (1960), during the fallow period, (1) more nutrients are accumulated in the standing vegetation than in the soil, (2) in the forest fallow there is evidence that a net transfer of nutrients from subsoil occurs as a result of deeper root penetration, (3) soils under forest contain more total phosphorous and calcium in the surface horizon than in the lower horizons and (4) amounts of exchangeable potassium, calcium and magnesium in the soil during fallow are smaller than the amounts in the aerial parts of the vegetation (Mouttapa 1974). The nutrient levels in aerial cover of fallow vegetation and soils are presented in Table 6.

In traditional farming systems, fallows are used for the maintenance of soil fertility and since the nutrients are carried in the aerial parts of the plant and in soil organic matter, sometimes to an extent greater than in the soil, practices such as burning affect the amount of organic residues that are returned to the soil and the loss of nutrients affect the productivity of the soil (Tables 6 and 7). Lengths of fallow under various types of shifting cultivation or bush fallow systems are presented in Table 8. A study of the data in Tables 6, 7 and 8 gives some idea of the amount of nutrients cycled in the traditional slash and burn clearing and associated cropping systems. Since the practices used are related to the objectives of the farmer and the resources at his disposal, various cropping systems are associated with different crop plant, weed, and plants residue management practices which determine the amount of organic matter and nutrients in the soil and the extent of beneficial or adverse effects they may have on the soil and crops grown. For example, harvesting of crops results in removal of nutrients (Table 9) which may be returned to the soil through various channels including the throwing away of nonfood or inedible parts of the harvested produce, waste materials thrown away during processing and preparation prior to storage or consumption, faeces and dead bodies of insects and rodents that consume various parts of plants after harvest, human excrement deposited in the bush, composts, decomposed nightsoil, etc. all of which in various ways find their way into the soil. The nutrient composition of various animal manures is presented in Table 10 and the annual production of major nutrients through organic wastes in developing countries is shown in Table 11. Table 12 shows the animal propulations in different parts of the world. Reference to these last three tables gives some idea of the numbers of animals, the nutrient composition of animal manures and amount of animal and other organic wastes that find their way into the soil and contribute to nutrient recycling.

Table 6

NUTRIENTS STORED IN THE AERIAL COVER OF FALLOW VEGETATION AND IN THE SOILS (AFTER NYE & GREENLANT 1960)

Location	Annual rainfall (mm)	Type of fallow	Nutrients stored in the aerial cover of vegetation and litter (kg/ha)					Nutrients stored in the soils in the first 30 cm (kg/ha)				
			N	P	K	Ca	Mg	N	P	K	Ca	Mg
Kade (Ghana)	1625	40 year old mature secondary forest	1863	128	833	257	352	4674	13	661	2622	376
Yangambi (Zaire)	1825	18 year old secondary forest	569	74	412	571		2280	19	365	102	54
Yangambi (Zaire)	"	5 year old secondary forest	398	24	350	298						
Ejura (Ghana)	1475	20 year old high grass savanna	27	8	47	35	26	1824	23	194	2964	388
Ejura (Ghana)	"	_Imperata cylindrica_	17	6	35	7	14					

Table 7

SOIL CHANGES FOLLOWING THE CLEARING AND BURNING OF FALLOW (AFTER NYE & GREENLAND 1960)

Location	Annual rainfall (mm)	Remarks	Soil depth (cm)	pH	C %	N (%)	P (ppm)	K	Ca	Mg	CEC
								meq/100 g soil			
Kade (Ghana)	1625	40 year forest fallow	0 - 5	5.21	2.22	0.22	9.8	0.41	5.7	1.21	10.1
			5 - 15	4.73	1.11	0.11	3.6	0.33	3.6	0.95	7.0
			15 - 30	4.63	0.87	0.08	1.9	0.32	3.0	0.94	6.7
		After clearing burning	0 - 5	7.9	2.26	0.19	30.0	2.01	17.9	2.7	9.9
			5 - 15	6.4	1.26	0.11	8.0	0.81	4.6	1.3	5.7
			15 - 30	5.7	0.94	0.08	5.0	0.42	3.0	1.1	6.4
Liberia	2000 to 4500	Before clearing	0 - 7.5	4.5	2.37	0.14	8.9	0.77	1.33	0.62	8.8
			7.5 - 15	4.1	1.35	0.08	9.2	0.17	0.59	0.38	7.9
		After clearing	0 - 7.5	5.3	2.77	0.15	18.0	1.22	2.67	0.90	10.6
			7.5 - 15	4.0	1.62	0.10	9.2	0.42	0.51	0.29	11.2
Benin (Nigeria)		Before clearing	0 - 15	5.0	1.16	0.08					5.6
			15 - 45	4.4	0.66	0.05					5.3
		After clearing	0 - 15	5.9	1.23	0.09					5.9
			15 - 45	4.5	0.65	0.05					5.2

Table 8 LENGTH OF THE CROP AND FALLOW PERIODS UNDER SHIFTING CULTIVATION

No.	Place	Annual rainfall (mm)	Crop	Fallow	Periods in the year				Typical value for R
					Normal		Excessive		
					C	F	C	C	
				Moist evergreen forest zone					
1.	Liberia	2 000-4 500	Rice, manioc	Forest	1-2	8-15			11
2.	Sierra Leone	2 300-3 300	Rice, manioc	Forest	1-5	8	1.5	5	12
3.	Nigeria (a) Umuahia	c. 2 300	Yams, maize manioc	*Acioa barteri*	1-5	4-7	1.5	2.5	21
	(b) Alayi	c. 2 300	Yams, maize manioc	*Anthonotha* ap.	1-5	7			18
4.	Central Congo	1 800	Rice, maize manioc	Forest	2-3	10-15			
			Moist semi-deciduous and dry forest zone (including humid zone of derived savannah)						
5.	West Africa	1 500-2 000	Maize, manioc	Moist semi-deciduous forest	2-4	6-12			25
6.	Abeokuta Nigeria	c. 1 300		Thicket			2	4-5	30
7.	Ilesha Nigeria	c. 1 300		Thicket	2	6-7			24
8.	Ivory	c. 1 300		Elephant grass	3	3	9	6	50 1/

Source: Nye and Greenland, 1960

1/ Semi-permanent cultivation in our terminology.

Table 9

NUTRIENTS REMOVED IN HARVEST OF COMMON NATIVE CROPS

	kg per hectare						
	Yield	N	P	K	Ca	Mg	Authority
Maize (grain only)	1 100	17.1	3.0	3.0	0.2	0.2	Morrison (1954)
Rice (paddy)	1 100	13.6	3.5	3.9	0.9	1.5	" "
Groundnuts (kernels)	(550)	(28.5)	(2.4)	(3.0)	(0.3)	1.0	" "
(shells)	(220)	(2.2)	(0.2)	(1.8)	(0.7)		
Total	770	30.7	2.6	5.3	1.0		
Cassava (fresh tubers, 30% dry matter)	11 000	25.0	3.3	66.0*	5.9**		Imperial Bureau (1936)
Yam (fresh tubers, 30% dry matter)	11 000	38.6	3.0	39.9	0.7		" " "
Bananas (fruits, 30% dry matter)	11 000	30.7	4.5	63.2	0.7		" " "
Cocoa (beans)	(550)	(13.6)	(3.2)	(11.4)			Adams and McKelvie (1955)
(husks)	(550	(11.4)	(1.2	(25.0)			
Total	11 000	25.0	4.4	36.4			

It is assumed that all other residues are left on the land

* Morrison's figure gives 35.3 kg

** Another determination gives half this amount.

Source: Nye and Greenland (1969)

Table 10

COMPOSITION OF ORGANIC MANURES FROM VARIOUS ANIMALS

Description	Moisture content (%)	Percentage composition					
		Total Ash	Soluble Ash	P_2O_5	K_2O	N_2	Location
Dairy, cow and pig manure with sweepings, grass, etc.	52.38			1.07	3.44	1.14	Ibadan
Pen manure (cattle rotted)	56.77			0.82	5.54	1.57	Ibadan
Pen manure as above	70.77			1.06	4.76	1.63	Ibadan
Pig manure (dry)	15.40	88.1	-	0.19	0.07	0.37	Umuahia
Sheep manure (dry)	10.60	79.2	-	0.30	0.34	0.48	Umuahia
Pen manure	24.24	62.55	9.55	0.49	2.33	1.03	Daura
Pen manure	45.65	54.40	16.41	1.16	2.47	1.87	Ilorin

Source: Phillips, T.A. (1964), An agricultural Notebook Ikeja: Longman Nigeria Ltd.

Table 11

TOTAL ANNUAL PRODUCTION OF SOIL NUTRIENTS (N, P, K) THROUGH ORGANIC WASTES IN THE DEVELOPING WORLD, 1971 (ACTUAL) AND 1980 (ESTIMATED) 1/

Source		(million metric tons of nutrients)		
		N	P	K
Human	1971	12.25	2.87	2.61
	1980	15.26	3.57	3.25
Cattle	1971	17.80	4.91	14.12
	1980	22.25	6.14	17.65
Farm Compost	1971	9.54	3.34	9.54
	1980	11.93	4.18	11.93
Urban Compost	1971	0.48	0.38	0.57
	1980	0.60	0.48	0.71
Urban Sewage	1971	1.43	0.29	0.86
	1980	1.79	0.36	1.08
Other 2/	1971	6.63	4.44	11.35
	1980	8.29	5.55	14.19
Total	1971	48.13	16.23	39.05
	1980	60.12	20.28	48.81

1/ Excludes Central America and Oceania, includes Socialist Asia.

2/ Bone meal, poultry litter, bagasse, sheep/goat litter, oil cake, press mud. (Several other sources were not included due to small potential for all developing world.)

Source: Singh (1974)

Table 12

THE FARM ANIMAL POPULATIONS OF THE WORLD

			No. of animals/100 people			
Region	Human Population x 10^6	Cattle and buffalo	Horses asses and mules	Pigs	Sheef and goats	Poultry
Europe	462	27	2	30	30	273
N. America	227	56	4	33	10	241
Latin America	284	88	15	36	60	242
Near East	171	27	6	0	120	98
Far East	1162	30	1	4	16	60
Africa	305	47	5	2	75	121
Oceania	19	175	3	18	1231	166
USSR	243	41	3	28	59	247
People's Rep. of China	850	11	2	26	15	138
World	3723	34	3	39	18	149

Source: Man, Food and Nutrition. Blaxter, 1975.

4. CROPPING SYSTEMS AND RESIDUE MANAGEMENT

The various farming systems in vogue in tropical Africa are listed in Table 1. While they differ in intensity and extent of association with animals, they entail certain operations which affect residue management and nutrient turnover. These practices include:

i. Land development and preparation
ii. Cultivations
iii. Cropping patterns
iv. Cultural practices (weeding and fertilizer application)
v. Pest, disease and weed control practices
vi. Harvesting
vii. Processing and utilization

For each of the following farming system and associated cropping systems the way the different practices are carried out determines the amount of plant residues and what happens to it.

4.1 Traditional and Transitional Farming Systems

In all traditional and transitional farming systems (1) land preparation involves the widespread use of slash and burn techniques, (2) bush clearing, tillage and harvesting are carried out with such simple tools as the matchet, hoe, axe, digging sticks and similar implements, (3) crops are grown in relay and intercropping systems without any systematic sole crop rotations, (4) cropping period is related to the distribution of rainfall during the year, (5) weeding is carried out by hand, mechanically with hoes and other related tools, (6) fertilizers are not usually widely used (except in cash crops) but organic residues, animal manures and various wastes may be used especially in compound farms and gardens, (7) costly chemicals are not used in pest and diseases control which may be done physically, culturally or not at all, (8) harvesting is done by hand and residues carried away from the farm are not as much as in mechanized harvesting and processing of certain crop by-products in more commercialized systems of production, and (9) processing is limited to that associated with their preparation for consumption and the non-edible parts of the crop are not usually utilized in industry as in the agriculture of some developed countries. For example almost every part of the rice plant is put to some use in Japan.

4.1.1 Shifting Cultivation (Phase I)

This farming system is not usually associated with animal production and is now almost absent from tropical Africa except for restricted parts of Northern Rhodesia (Zambia), Allan (1965), Ivory Coast and the Nigerian/ Cameroun border (Morgan 1969, Grigg 1974).

Land clearing is carried out with the slash and burn techniques in which forest cover may not be completely destroyed since only small shrubs, climbers and herbaceous plants are slashed and burnt and large trees or economic trees are left standing and these may continue nutrient cycling as in the original forest. Burning destroys soil organic matter and predisposes it to loss by erosion but makes nutrients more readily available to the crop. Extent of destruction of soil organic matter will depend on the intensity of burning and time of burning - the more intense the burn and drier the material the more the destruction of soil organic matter and reduction of residual effects of organic residues. Burning may be carried out on residues left on the soil surface or buried in the ground (Hawkins and Brunt, 1965). Burning in general usually results in decreases in organic carbon, CEC, soil nitrogen, and populations and activities of various organisms that may facilitate decomposition and enhance nutrient turnover at various depths in the profile.

Extent of preplanting cultivation is variable but it is usually minimal in friable soils except for root crops and soils subject to high water table and flooding or very heavy soils where mounds, beds or ridges are used and within which residues may be buried. Soil disturbance, damage to soil structure and its predisposition to erosion, nutrient loss and poor cover development which adversely affect future plant growth and residue accumulation is not as pronounced as with mechanical cultivation for row crops in large scale commercial enterprises.

Cropping patterns are related to the prevailing rainfall distribution and intercropping not only of annuals but also annuals and perennials in the most widespread practice. This practice when carried out at not too wide a spacing provides quick soil cover and the different crop species with their root systems at different levels are more efficient in utilizing and recycling nutrients. Intercropping also helps to suppress weeds which usually have to be pulled out or scraped off with simple tools. Where weeds are left on the surface they may augment the organic matter on the soil surface at least temporarily but clean weeding as often achieved with tillage implements or herbicides in row crops of developed countries in temperate regions is rare.

Harvesting, processing and storage does not involve removal of both edible portions of the plant and other parts for industrial use but dead stumps, staking materials, etc. may be used as firewood and the ash together with household refuse may later be used as fertilizer in the homestead gardens and adjacent farmland.

Households may be moved so that soil around them where nutrients from ashes and leaf litter are concentrated may be utilized for cropping in certain cropping systems of central Africa. Data on nutrients removed with harvested crops are presented in Table 9.

4.1.2 Shifting Cultivation Phase II: Bush fallowing or land rotation

The general practices used in crop production under this system are almost the same as under Shifting Cultivation (Phase I) except that each farmer definitely operates a permanent compound garden and several field systems at varying distances from the household with periods of fallow depending on population pressure. On the compound farm only small animals are usually kept and larger animals such as cattle are absent or very few due to trypanosomiasis being endemic in the region. Dung from pens, ash from the kitchen, human waste and household refuse are used for the maintenance of soil fertility necessitated by the reduced fallow periods or continuous cropping that is practised on such gardens. The cropping systems are very complex and involve mixtures of tree crops, plantains, starchy staples, fruits and vegetables. These result in agro-ecosystems which approach the multi-storeyed forest ecosystem of the humid tropics in stability. Accumulation of organic matter in the tropics is however, limited by high temperatures, extent of annual burning during clearing, removal of materials through harvesting for food and various products and grazing by small livestock. Consequently, the extent of organic matter accumulation approaches but does not reach the same extent as under forest. Nutrient cycling by trees, shrubs and herbs and reduction of erosion except along foot paths and on constantly swept compounds and market places are similar to what occurs under bush fallow or forest. Thus crop production in the permanent compound farm or garden is intensive and fertility maintenance is at the expense of plants grown and whose materials are collected in one way or another in the surrounding areas in the form of small animal pen manure and droppings from browse plants, kitchen and compound refuse, ashes, human excrement, organic waste from structural materials used in building, manufacture of utensils, etc. It is for this reason that as indicated below the pH, calcium, magnesium, potassium and phosphorus levels and general soil fertility are higher than from soils on farms outside the compound farm (Lagemann, 1977).

On other farms and different field systems associated with each compound or homestead garden fertility is maintained by fallowing for different periods with (1) purposely planted fallows or *Acioa bateri* and *Anthonotha macrophylla*, (2) specially selectively protected bushes in which the dominant and abundant species consist of *Alchornea cordifolia*, *Acioa bateri*, *Anthonotha macrophylla*, *Harunga madagascariensis*, *Dialium guineense*, and about 60 species including *Cnestis ferruginea*, *Uvaria chamae*, *Monodora tenuifolia*, *Napoleona vogelli*, etc. as common species (Obi and Tuley, 1973), and (3) naturally spontaneous bush and herbaceous plant regrowth which has been in varying degrees modified by man on different soil types ranging from scrubby bushes dominated by herbaceous weeds and grasses including, for example, *Eupatorium odoratum*, *Panicum maximum*, *Andropogon tectorum*, *Aspillia africana*, *Mikania cordata*, etc. in over-cultivated areas of southeastern Nigeria (Obi and Tuley, 1973) to well developed secondary woodland, bushes and forests of the kind reported by Hawkins and Brunt (1965) in the Cameroun and Nye and Greenland (1960) in Ghana. Where only herbaceous species abound in over-cultivated areas, plant succession may eventually develop into dominant vegetation of *Imperata cylindrica* in very poor soils or *Pteridium aquilinum* (Obi and Tuley, 1973) and nutrient cycling is limited to the surface layers of the soil and the amounts of vegetative growth and litter are greatly reduced. With deep rooted shrubs and trees in areas of longer duration fallows, forest productivity and nutrient cycling approach those reported in Nye and Greenland (1960) in Ghana and nutrient levels in plants and soils tend to stabilize and approach forest conditions after 5 years.

4.1.3 Shifting Cultivation Phase III: Rudimentary Sedentary Agriculture

This farming system involves higher intensity of cultivation, reduced size of farm holdings and much shorter periods of fallow than in Bush Fallow or Land Rotation Systems. It is found in areas of high population density such as parts of southeastern Nigeria as described in some detail by Floyd (1969). From the spatial and locational aspects of distribution of farming systems, these farms exist between areas of very dense population concentrations where farms consist more or less of compound farms and areas of lower population density and longer periods of fallow. They also occur on the periphery of large urban concentrations such as Ibadan in south-western Nigeria. Permanent cultivation in the compound garden is the same in the Bush Fallow system described above but the field systems associated with the compounds are located closer to them, are under shorter periods of fallow and may contain both annual staples during the cropping cycle and more of regularly planted perennial tree crops of compound farms such as *Dacryodes edulis*, *Cola* spp, *Citrus* spp., etc., than the higher populations of protected useful plants of more distant fields in the Bush Fallow system such as *Dialium guineense* and *Pentaclethra macrophylla* in southeastern Nigeria.

In this farming system, farm practices, cropping sytems, agro-ecosystems, nutrient cycling and fertility maintenance are similar to those of compound farms and fields closest to the household garden. Fertility maintenance and productivity may very well depend on the inherent soil fertility since the area of land from which nutrients can be concentrated and periods of fallow are greatly reduced.

4.1.4 Compound farming and intensive subsistence agriculture

These are the most intensive farming systems of the humid tropics - production systems very similar to horticulture and market gardening in which fertility maintenance depends heavily on various organic manures, household and kitchen refuse, farm yard manure, compost and sometimes rotations involving legumes such as *Crotolaria* spp. as reported by Floyd (1969) and Morgan and Pugh (1969) in Eastern Nigeria and Bamenda area of southwestern Cameroun and by Ruthenberg (1976) for more arid areas of the tropics on densely populated and intensively farmed Ukara Island on Lake Victoria.

In southeastern Nigeria there are extensive areas of the usual intensively farmed compound gardens and surrounding equally but slightly less intensive farms associated with areas of high population density. Fallows are absent or limited to one or two years and permanent cultivation is therefore widespread. This part of the country resembles a series of adjacent compound farms on which annual starchy staples, vegetables, fruit trees, and other tree crops such as oilpalms and coconuts are grown. Nutrient cycling here involves herbaceous and perennial weeds, shrubs, trees, and animals. Unlike the other traditional farming systems described above, the intensive agriculture often involves some rotation of crops. In south-eastern Nigeria, each year of cocoyams intercropped with some maize and vegetables (to which high rates of household refuse, farmyard manure, mulch from prunings of trees to reduce shade, crop residues, etc., are applied to maintain soil fertility) alternates with a year of yams intercropped with maize and vegetables and later relay intercropped with cassava. Usually much less organic residues are applied directly to the yam crop - a practice which is claimed to reduce nematode damage. This is followed after harvest of cassava by a year of fallow or reversion to cocoyams.

All the time these crops are intercropped with perennial crops including bananas and plantains, the leaf litter of which are involved in nutrient cycling but it is not known to what extent these may counter-balance what is carried away in the useful products which may be sold off the farm or consumed on the farm. It is interesting to note that on these farms the continuous cultivation and continuous shade limit weeds to such perennial species as *Icacina mannii*, and *I. senegalensis*, stumps of *Mallotus subulatus*, *Mallotus oppositifolius*, *M. subulatus*, *Napoleona vogelli* and *Clerodendron* spp. and few herbaceous species such as *Ageratum conyzoides*, *Commelina* spp., *Spigelia anthelma*, *Croton lobatus*, *Triumfetta* spp., *Boerhavia diffusa*, *Portulaca* spp., *Eupatorium odoratum*, various species of sedges, etc.

4.1.5 Terrace farming and flood land agriculture

Terrace farming is not as widespread and intensive in tropical Africa as in the paddy rice system of Southeast Asia. In West Africa, some terrace farms have been developed on defensive hillsides during the slave trade. Details of farming systems of this kind for Maku area of southeastern Nigeria are given by Floyd (1969) and Dema (1965). On terraces built on steep hillsides intensive crop production involving mainly annual staples and vegetables are made possible by application of compound manures and organic residues.

In the Maku area of southeastern Nigeria most of the tree crops are limited to compound farms and the deeper valley bottom soils. Number of years of fallow is low and range from 0 - 2 years on the terraces. Nutrient cycling involves small animals and trees on compound farms and mainly herbaceous weeds and crops that grow on the terraces. The manurial value of composts, farm yard manure and other organic residues which may be used on compound farms and vegetable gardens are presented in Table 9. Nutrient cycling processes on intensively farmed terraces are similar to those of compound farms, homestead gardens or market gardens. The conditions in the valley bottom lands approximate those of Rudimentary Sedentary agriculture except that they also involve aspects of flood land agriculture in the silt or alluvial material carried down the slopes and deposited in the valleys. Flood land agriculture occurs along the shores of the major rivers such as the valleys of the Niger at Oguta in Nigeria, the Volta, the valleys of the Anambra, a tributary of the Niger and other rivers. The soils are seasonally inundated and on these alluvial soils, yams, rice, maize and vegetables such as melon, fluted pumpkins (*Telfairia occidentalis*) and okra are grown. Nutrients available to the crops are annually brought down by runoff and erosion in the watersheds of the rivers concerned, but the farmer who has to race with the flood grows only crops that must be harvested before the next flood season whether they are mature or not. *In situ* nutrient cycling involves only the residues of crops and weeds growing during the non-flood periods of cropping and only a small quantity of the nutrients taken up by the growing crop will be available to the crops that will be grown during subsequent growing seasons. Some may be available to crops in subsequent years if the organic residues are not carried away to other locations or to the sea and if the decomposed debris is within the rooting zone of the crops. Flood land areas along the major rivers in the humid tropics of Nigeria are the areas where the best yam crops are produced. On such soils fertilizer application is usually not necessary for high crop yields.

For the different cropping systems reviewed above, the nutrient cycling and the extent of removal in harvested produce may vary somewhat in various crop dominance regions (see Morgan and Pugh, 1969). For example, in the southwestern parts of West Africa west of the Bandana river in Ivory Coast (e.g. Sierra Leone and Liberia) rice is dominant and may be grown with maize and cassava but east of the Bandana river in parts of Southern Nigeria, Togo, Dahomey and Ivory Coast, root crops are dominant. Similarly, in southwestern Cameroun and the adjacent area of Nigeria, plantains and cocoyams are dominant but in the remaining areas roots and cereals predominate. Different crop dominance regions have been described in the Congo and Central Africa by Miracle (1967).

4.2 'Modern' Farming Systems and Their Local Adaptations

While local modifications of traditional farming systems has occurred and is still continuing in response to changes in socio-economic conditions and need for increased commercialization, attempts have been made to develop new systems by adopting those developed elsewhere and/or modifying them to suit local conditions. Thus more commercialized farming systems have been developed for growing crops such as cocoa and groundnuts which are the major revenue earners for some developing countries of tropical Africa especially in the absence of rich mineral deposits. This heterogeneous group of farming systems include livestock production systems, large-scale plantations, and specialized horticulture.

4.2.1 Mixed Farming

This farming system involves the association of animal production with crop production. It is more well developed in the drier savannah areas where tsetse flies are absent and cattle can be kept for meat, milk and other products, work and manure. Most of the farming systems of the humid tropics are diversified enterprises which strictly speaking may also be regarded as mixed farms because the compound farm system which is associated with the various fields usually involves small livestock such as poultry, sheep, goats, pigs, and in a few locations dwarf short-horn cattle resistant to trypanosomiasis. Lagemann (1977) reported total number of livestock of various kinds in Okwe Umuokile and Owerri-Ebeiri areas of Imo State of southeastern Nigeria where human population densities were low, medium and high to be 286 462 and 611, respectively. On the average each household owned 2 goats and 15 chickens. The higher the number of livestock on the farm the more the nutrient cycling involves the passing of the plant material through livestock before they are returned to the soil. The small animals feed on grasses and browse plants either on free range as in the dry season or tethered in selected locations in fields or compounds. Poultry usually fend for themselves. Both poultry and small livestock are occasionally given a few grains of maize, other cereals, or peelings and crop residues from the farm and kitchen.

4.2.2 Livestock Ranching

This involves extensive livestock production often based on grazing of natural ranges. It is not possible in the humid tropics except in isolated highland areas such as the Obudu cattle ranch in the Cameroun border of Nigeria. Here temperate cattle have been introduced and are grazed on natural pastures on which recently some introduced forage grasses and legumes were interseeded. Limited fertilization is involved and nutrients move from the soil to the plant and then into the animal which feeds on the forage. Droppings are later passed out by the animal and excess nutrients find their way into the soil from where they are recycled again or lost through runoff and erosion especially where there is overgrazing.

4.2.3 Intensive Livestock Production

This often occurs close to urban centres and involves keeping of poultry, pigs and rarely dairy cattle. They are usually commercial enterprises in which a lot of capital is devoted to the purchase of animal feed. Poultry, pigs and cattle are fed with different amounts and proportions of feed that may be grown on the farm but a major part of the concentrates are purchased from outside the farm.

The nutrient cycling involves plants and animals but it is not on all the farms that the manures are returned to the soil for crop production. Depending on the management, a lot of the nutrients may be lost in sludge and effluent from animal pens which eventually find their way to the drainage water which runs into streams, rivers and lakes. The nutrient content of cattle manure as compared to other organic wastes used in developing countries are shown in Table 11. Sometimes more efficient use are made of farmyard manure, farm effluent and other wastes in the growing of food crops especially vegetables on the same or other farms or spread on the pasture and recycled through the system over and over again. The major nutrients that leave the system under these conditions are in the form of animal products which are sold or otherwise consumed and utilized off the farm.

4.2.4 Large-scale plantations

(a) Large-scale food and arable crops

These constitute attempts to copy the arable crop production systems of temperate countries and involve greater use of fertilizers, pesticides and mechanization than in traditional farming systems. Long duration fallows may be replaced by one or two years of leguminous covers and fertility is maintained with fertilizers. Most of the products are sold and crop refuse is usually ploughed into the soil where some nutrients from it may be lost through runoff, erosion and leaching. Here the native vegetation with the exception of some weeds is of little importance in nutrient cycling. These production systems have not always been successful and some have been disastrous failures due to poor soil management and neglect of certain relevant ecological considerations.

(b) Irrigation projects

Most of these are restricted to savannah areas but supplementary irrigation and use of water from rivers and streams in paddy rice production is increasingly being practiced in the humid tropics of West Africa. Nutrient cycling is similar to that of other arable crops but while in some situations fertilizers may be used, in other crops may depend on rich alluvial deposits in hydromorphic soils. Under paddy conditions, plants such as Azolla with associated green algae or free living algae may be involved in nutrient cycling. Since these are strictly commercial enterprises more of the nutrients are lost by their being taken away in the harvested produce.

(c) Large-scale tree crop plantation

These are commercial tree crop production systems which were first developed in southeast Asia where labour was cheap and expatriate managerial staff of colonial firms and capital from developed countries were harmonized to ensure production of materials needed for export to support industries in Europe. In these systems more fertilizers are needed as plantations get older. Trees with deep root systems collect nutrients from deep down the profile while leguminous cover crops are able to fix atmospheric nitrogen which become available to the tree crop. With continuous cultivation of plantation crops minor element deficiencies may eventually show up and these are treated by foliar or other methods of fertilizer application. In general, in this type of farming system, very limited amounts of nutrients are lost through leaching or runoff. Most of what is lost is in products carried away and the amount recycled is also limited to the extent that litter is left on the surface, burnt or otherwise returned to the soil.

4.2.5 Specialized Horticulture

(a) Fruit trees and/or ornamentals

In these crop production systems nutrient cycling is similar to that which obtains in tree crop plantations since the practices, processes and production systems are similar. With ornamental crops, however, fertilizer use may be minimal since the density of planting is usually very low except for annual herbaceous ornamentals. Nutrient removal through harvesting does not occur where ornamentals are not cut and sold or used for decoration. Ornamental horticulture is still in its infancy in the humid tropics of Africa.

(b) Market gardening

This involves intensive production of vegetables close to urban centres. This cropping system may depend on composts, urban wastes, manures and/or fertilizers from livestock industries for the major part of the nutrients required by the plant and for the maintenance of soil fertility and productivity. They are also practised on hydromorphic soils where off-season vegetable production is very lucrative and depends on nutrients derived from the slopes and upland areas which are deposited in the valley bottoms or depressions. Nutrient cycling processes here are similar to those of compound farms except that the production is mainly commercial and may be highly intensive and seasonal. Fertilizers and/or manures may be applied but usually the soils are rich enough to support crop production with minimum fertilizer application. Most of the nutrients are carried off the farm in harvested produce each season. Some nutrients are lost by leaching and runoff especially in sandy soils, on steeper upper parts of the valley bottoms especially in the absence of vegetation cover or mulch and under irrigation.

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Paper 2

CROP RESIDUES IN TRADITIONAL CROPPING SYSTEMS OF WEST AFRICA - EFFECTS ON THE MINERAL BALANCE AND LEVEL OF ORGANIC MATTER IN SOILS - PROPOSALS FOR THEIR BETTER MANAGEMENT

J-F. Poulain [1]

1. GENERAL STATEMENTS ON ORGANIC MATTER AND THE RECYCLING OF CROP RESIDUES

In view of the difficulty in comprehending all the constituents of organic matter in their dynamic state, under the term Organic Matter, agronomists usually denote:

- organic substances of plant, animal and microbial origin found in the soil at any given moment;
- the complex of organic compounds being incorporated into the soil (indirectly or directly by ploughing) which result in maintaining or increasing its fertility.

This complex embraces on the one hand bush, fallow and green manure crops and on the other hand, crop residues. The latter may be used without transformation (aerial parts and roots) or converted on reduction in mass into more elaborate compounds such as composts and manures.

Discussion will be restricted to crop residues, and their role in the mineral and organic scheme will be examined first.

1.1 Crop Residues: Essential Factor in the Mineral Balance

1.1.1 Factors of the mineral balance

To establish the fertilizer requirements of a crop system the mineral elements needed by all the plants in the system must be determined. This implies a knowledge of two factors:

- the dynamics of the elements studied in the soil, e.g. knowledge of deficiencies;
- the requirements of the plants in the pedoclimatic and cultural conditions selected and according to expected yields.

This leads to the definition of two essential concepts:

- corrective fertilization of soil deficiencies;
- maintenance fertilization adapted to the plants in the system.

Corrective fertilization is defined as the quantity of a given nutrient required for maximum yield. It implies on the one hand an optimal supply of water and other mineral elements needed by the plant and, on the other hand, good husbandry practices so that no other factor is limiting.

Maintenance fertilization must compensate for the nutrients taken up by crops and lost by runoff, erosion and leaching. The idea is to reach a zero balance at the plot level. The full importance of maintenance fertilization comes out only when fertility has been raised by corrective fertilization.

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It is worth noting that fertilizer formulae currently recommended in West Africa try for the most part to fulfill the two roles at the same time. Most frequently they provide for the correction of the widespread soil deficiency of phosphorus and the essential needs of crops. Nitrogen fertilization, especially for cereals, is always recommended but it is often supposed that the other elements, particularly potassium, are provided by the reserves included in the soil. These formulae aim only at stimulating peasant production, rapidly and at least cost, in order to allow him to satisfy subsistence needs and to have some surplus for sale. However, in cases where the formula adds elements in quantities more than the maintenance dose, a reserve is being built up in the soil.

The establishment of the mineral balance of a crop system is thus an essential operation, but often difficult to realize precisely. Losses of mineral elements (runoff, erosion and leaching) may be estimated from measurements taken in erosion and runoff plots and by using lysimeters. These data are often approximate and the results vary widely according to the year, the crop, the level of yield and the nature of the soil. It seems easier to determine by analysis the uptake of mineral elements and to distinguish the amounts removed in the harvest. The difficulties are still numerous, for the requirements of plants depend on numerous factors type of plant, variety, present soil fertility. The level of yield is an essential factor which in turn depends on numerous others often difficult to control, rainfall being among the most important for rainfed crops. Nevertheless, the main requirements of plants have been worked out and the results of determinations made in different countries of the Sudano-Sahelian zone are in agreement.

The mineral elements included in recycled crop residues must be deducted from the maintenance fertilizer requirement which can be calculated from the total uptake of the plant. In the following section an example of the mineral balance for a very simple cropping system is presented. It shows the importance of treatment of crop residues in determining the maintenance fertilizer requirement.

It is pointless to think of using crop residues exclusively, even transformed, for the correction of soil dificiencies. The nutrient reserve aspect must also be considered. In fact, the harvest and the residues, transformed or not, are only a reflection of the soil. Thus, manure will generally be very poor in phosphorus and one application, even at a high rate, may induce an imbalance in soil deficient in phosphorus; the other elements, potassium and nitrogen in particular, may become excessive. Moreover, the exclusive application of manure, for example, may be viewed as a soil-impoverishing practice by transferring fertilizer elements from one zone (pasture, distant arable fields) to the benefit of another (fields around the homestead), without real compensation. This problem of transfer of fertility merits particular attention.

1.1.2 Example of approximate mineral balance

The mineral balance presented concerns the element potassium. It was worked out in Upper Volta (1). The cropping system selected is a simple binary one: cotton-sorghum. This system is frequently observed, maize being substituted for sorghum in the South-West zone. It comprises two plants with different rooting patterns and different uptake curves for potassium: cotton is a plant with a high initial demand but an overall medium consumption, sorghum by contrast shows a medium but more sustained absorption. It is always better to establish the net balance at the level of the cropping system.

Two variants have been retained, the characteristics of which are set out in Table 1. Each of these variants has been studied according to two hypotheses –

Hypothesis I: cotton stems burnt
sorghum straw removed

Hypothesis II: cotton stems burnt
sorghum straw returned (burnt or ploughed in)

Hypothesis I corresponds to the Centre North zone where crop residues are put to many uses and consequently almost all residues are removed.

In the South-West zone sorghum straw is often left in the field after harvest and burnt at the time of land preparation. The losses of potassium have been extrapolated from the results of studies on runoff, erosion and drainage carried out at Saria from 1971 to 1974 by Roose (ORSTOM), Arrivets and Poulain (IRAT) (2). They are relatively small, but apply to soils on gentle slopes where the phenomena of runoff and erosion are well controlled. The additions in rainwater are the mean of measurements recorded at Saria over three years in the study already cited.

The approximate mineral balance for potassium is presented in Table 2.

Table 1

CHARACTERISTICS OF THE SYSTEMS

	System A	System B
Region	Centre North	South-West
Parent rock	Granite	Sandstone
Soil type	Ferruginous tropical soil on petroplinthite at 50 cm	Moderately deep weakly ferrallitic soil
Slope %	0.5%	0.5%
Clay (0–20 cm)%	10.5%	9.5%
K total ‰ (0–20 cm)	4.5‰	1.0‰
K exch. meq/100 g (0–20 cm)	0.14 meq/100 g	0.11 meq/100 g
Average rainfall	800 mm	1100 mm
Yield { cotton seed	1 t/ha	1.6 t/ha
sorghum grain	1 t/ha	1.8 t/ha
Cultural practices	optimal	optimal
Losses { runoff erosion drainage	20 kg K_2O/ha/year	20 kg K_2O/ha/year
Additions in rainfall	4 kg K_2O/ha/year	4 kg K_2O/ha/year
Inorganic fertilizers		
cotton	19 – 35 – 0	50 – 50 – 30
sorghum	32 – 18 – 0	65 – 35 – 30

Table 2 THE APPROXIMATE MINERAL BALANCE FOR POTASSIUM (kg K_2O/ha) UNDER SYSTEMS A AND B

			Hypothesis I		Hypothesis II		Balance over 2 year cycle	
	Crops	Nature of gains and losses	Gains	Losses	Gains	Losses	Hyp. I	Hyp. II
System A	Cotton 1 t/ha	(Stems burnt) Uptake	-	15	-	15	-64	-52
		Losses	-	20	-	20		
		Rainfall	4	-	4	-		
		Fertilizer	0	-	0	-		
	Sorghum 1 t/ha	(Straw removed) Uptake	-	17	-	-		
		Straw recycled	-	-	-	5		
		Losses	-	20	-	20		
		Rainfall	4	-	4	-		
		Fertilizer	0	-	0	-		
System B	Cotton 1.6 t/ha	(Stems burnt) Uptake	-	24	-	24	-27	- 5
		Losses	-	20	-	20		
		Rainfall	4	-	4	-		
		Fertilizer	30	-	30	-		
	Sorghum 1.8 t/ha	(Straw removed) Uptake	-	31	-	-		
		Straw recycled	-	-	-	9		
		Losses	-	20	-	20		
		Rainfall	4	-	4	-		
		Fertilizer	30	-	30	-		

Inspection of Table 2 shows, on one hand, the impossibility of attaining a mineral balance in the absence of appropriate fertilization (Hypothesis I) even at a modest level; on the other hand, the value of recycled crop residues (Hypothesis II) enables a reduction in the mineral deficit and a mineral balance is almost reached in the presence of fertilizer.

1.1.3 Need for a long-term agronomic approach to establish fertilizer requirements - Contribution of crop residues

The cost and profitability of mineral fertilizers is a permanent concern of developing countries, especially those in which the ratio between the cost of the mineral fertilizer and the price of the primary product is very wide. Most of these countries have been driven to subsidizing liberally the fertilizer distributed to farmers. Thus, in Upper Volta, the price of cotton fertilizer sold to the farmer at 35 F. CFA was raised by 75 F. in 1977, and in 1976 Senegal granted a subsidy of more than 3 thousand million CFA on mineral fertilizers. One, therefore, heartily agrees with the insistence of those in high places on the application of fertilizer formulae where they are economically profitable in the input/output ratio conditions which actually prevail. Moreover, these formulae must satisfy the incentive criterion which is established, according to FAO, at an acceptable level when the value of the increase in yield obtained is at least double the cost of the mineral fertilizer used to produce it.

This short-term socio-economic approach is often the only step taken; the mineral balance corresponding to the complex of crops in a rotation is rarely considered (3).

Yet for the agronomist for whom the long-term rationale is essential, it is imperative to maintain a positive balance or at least equilibrium between gains and losses. A balance regularly negative, even though satisfactory in economic terms, is unacceptable, for it masks in reality a regular decline in the fertility of soils by exhaustion of their reserves. The consequences in terms of absolute crop yields, no doubt hardly visible or slight in the short term, will not fail to be revealed in the medium and long term in the overall agricultural production of the country. It must not be forgotten that the harvest of a field not receiving any fertilizer is produced, save in exceptional cases, from the mineral elements existing in the soil which constitute its current fertility. If one admits only that this nutritive capital must be maintained by additions compensating the losses, it must equally be recognized that each maintenance dressing is necessary in its entirety to produce the totality of the crop. For Barbier (3) and from this point of view, "the calculation of the profitability of maintenance dressings has hardly more sense than if one proposed, for example, to calculate the profitability of using seeds in the production of a crop." The same research worker declares: "Rather than calculate the immediate saving from withdrawing these fertilizers from use, it would be preferable to try to forecast the increasing losses of money which would be suffered by the farmer or his successor in 5, 10, 15 or 20 years, in the prolonged absence of maintenance fertilization."

Numerous experiments conducted by IRAT in many countries have provided evidence for this delayed negative effect of the absence of fertilizer or of the repeated application of insufficient and incomplete dressings accompanied by a deficit mineral balance. The reports on the results of these experiments always draw the attention of those responsible to the fact that the fertilizer proposals worked out from socio-economic considerations must only be provisional and lay stress on the grave dangers of their acceptance as definite propositions.

Interesting work has been done by scientists at ISRA (Senegal) who have attempted to reconcile both the socio-economic and the agronomic approaches. They have succeeded in describing the conditions in which mineral fertilizers overcome agro-socio-economic constraints as a function of the input/output ratio (4). These authors have established the production functions of bulrush millet with nitrogen and potassic fertilizers on the very sandy weakly leached ferruginous tropical soils of Senegal. It is important to note that these are very different according to whether straw is returned or not.

Thus, for nitrogen fertilizer, it is possible to find dressings which satisfy agro-socio-economic constraints according to current cost/price ratios, but the determinations show the possibility of finding acceptable dressings as a function of these three criteria for wider cost/price ratios if millet straw is recycled.

For potash fertilizer, the situation is more precarious for in the absence of return of straw, there is no acceptable agro-economic solution because the balance between gains and losses is always negative. With recycling of crop residues, a solution may be found provided the cost/price ratio does not exceed the value of 4. Even in these conditions the margin is narrow, for a 45% increase in the cost of fertilizer would bring us back to the first state, that is to say, the impossibility of satisfying the three agro-socio-economic criteria (5).

Similar experiments have been conducted in different pedoclimatic conditions in Senegal (6). At Nioro du Rip in the south of Saloum, a spectacular effect of the ploughing in of rice straw equivalent to 90 kg/ha K_2O on the growth of the succeeding maize crop has been noted. For the inverse succession, we observe at Sefa in middle Casamance that the ploughing in of maize residues annuls the effects of potash fertilizer on upland rice. The point here is the effective mineral contribution of crop residues since going by strictly socio-economic criteria the cultivation of upland rice following maize with straw ploughed in would not require potassium fertilization and the agronomic constraint could be satisfied by moderate additions.

Certainly, as emphasized by C. Pieri, the agro-socio-economic method of interpretation remains undoubtedly approximate. Thus, the requirements of the plants are probably overestimated by the method itself, "Response curves by a sole crop", for in practice it is rare that all mineral elements, save the one which is being studied, are at the optimum. By contrast, the losses by leaching, runoff and erosion remain difficult to measure and are very probably underestimated under sorghum cultivated downslope, this being gentle: 0.7%, the annual losses are respectively 9 kg/ha K_2O by runoff, 28 kg/ha K_2O by erosion and 2 kg/ha K_2O by vertical drainage from the ferruginous tropical soils over petroplinthite at Saria, Upper Volta (1, 2).

The authors conclude (4) "For the agronomist, it is important to know that in each environment there actually exists a situation of mineral equipoise which one never quite attains ... the major objective will be the search for significant parameters in the evolution of the ecosystem, so as to know in advance when it will be necessary to interfere in the plan of the practical farmer in order to prevent an otherwise permanent degradation of the basic capital, at all events an obvious drop in production."

1.1.4 Mineral returns in cropping systems

The few examples cited have made clear the importance of crop residues in the achievement of a mineral balance. Before reviewing the principal crops featuring in the most widespread production systems of West Africa, it is important to specify the factors which determine the nature and magnitude of returns.

i. Factors influencing the nature and importance of returns

The most important factors are:

- the production system
- the crop rotation
- the variety of each crop in the system
- the level of production.

a. The production system

It is clear that a production system which integrates agriculture and livestock rearing affords room for the diversification and transformation of harvest residues. Besides the interest of using animals for tillage operations, ploughing in particular, the presence of oxen on the farm permits the following operations:

- transport and storage of harvest residues for the dry season

If it is reasonable to envisage the consumption of harvest residues directly in the field, it is prudent to envisage transport and storage of a part of the by-products for the feeding

- of animals in the dry season. This will limit the losses due to fire and theft.

The cart, indispensable for maintaining the work habits of oxen trained in the dry season, thus constitutes an important means of incentive to draught cultivation.

- pumping and transport of water

Water is an essential element for human and animal nutrition, but its avilability in greater quantity on the farm will permit the preparation of good quality compost and farmyard manure.

- transformation of residues into farmyard manure

In such a production system the utilization of crop residues for other purposes than the feeding of animals must remain very marginal. The problems of transport and water supply being resolved, it appears possible to envisage the preparation of farmyard manure with the addition of stable litter. Of course the feeding of animals will remain in part assured by the right of pasture, but in these systems the by-products of harvest must take a more and more important place.

b. The crop rotation

We have insisted on the essential fact that the presence of cattle on the farm gives a fundamentally different orientation to the treatment of crop residues and enables their practically complete recycling.

Confining ourselves now to the cropping system, we shall recall that two crops which succeed each other on the same plot are not independent. Thus, one crop modifies by its presence the state of the soil directly by its plant parts and indirectly by the husbandry practices which are applied to it (7). Thus, cotton after maize differs markedly from cotton after sorghum. By reason of the life cycles of the two cereals and the compaction of the soil after the cessation of rains it is possible to plough in the stover after the maize harvest but this operation is impossible after the sorghum harvest considering the varieties at present available. In the former case, it will thus be possible not only to recycle the harvest residues but also to sow the cotton early after one cultivation. After sorghum, the farmer is forced to remove the residues and either transform them into compost or farmyard manure, which is preferable if facilities are available, or else to burn them. He will then wait for sufficient rain to carry out land preparation and probably a second rain to sow the seed, which must be done at the optimum period. Owing to the long growing period of cotton, late sowing is generally accompanied by a drop in yield.

The nature of the rotation is therefore essential and one may henceforward assert that the more the proportion of crops with plentiful residues is increased in the rotation (particularly in the case of the traditional cereals millet and sorghum), the more will it be necessary to recommend the recycling of these residues on account of their important uptake of mineral elements.

Where residues are abundant it will no doubt be possible, if recycling is very effective, to solve the organic matter problem.

c. **The variety**

It is clear that the uptake of minerals by plants depends also on the cultivar. If we are acquainted with the average requirements of maize, rice, sorghum, etc., we are only dealing with approximate values which vary with the variety whose exact chemical composition is not always well known. However, determinations have been carried out on the principal varieties recommended for popular use. Thus, J. Dubernard in Cameroon (8) and M. Deat in Ivory Coast (9) have shown that there are numerous variations in the mineral content of cotton varieties: American varieties, BJA of Cameroon, 442 of Ivory Coast.

The quantities of elements removed in aerial residues in kg/t of seed cotton are shown in Table 3.

Table 3

ELEMENTS REMOVED IN THE AERIAL RESIDUES IN KG
FOR A HARVEST OF ONE TONNE OF SEED COTTON

	N	S	P	B	K	Ca	Mg
USA (1955)	46		8.0		55.0	18.0	9.0
Cameroon (1972)	60	7.5	8.0	0.07	59.0	29.0	11.0
Ivory Coast (1974)	36	3.6	4.5	0.04	41.5	18.4	5.0

(after M. Deat and G. Sement, IRCT, Ivory Coast)

Besides these varietal differences, the authors note the importance of variations in dry matter weight of residues for the same production of fibres among the varieties considered and for one variety according to climatic conditions.

Similar studies have been carried out on sorghum and figures are given of three sets of results, obtained in Senegal (10), in Upper Volta (11, 12) and in Cameroon (13) in analogous production conditions.

Table 4

ELEMENTS REMOVED IN THE AERIAL RESIDUES
FOR A HARVEST OF ONE TONNE OF GRAIN

	N	P	K	Ca	Mg
Senegal (SH 60)	12	1	10	9	9
Upper Volta (S. 29)	19	3	33	8	7
Cameroon (IRAT 85)	7	3	24	7	6

It is shown that the amounts of phosphorus, calcium and magnesium removed are relatively constant. More than half of the P is recovered in the aerial residues which contain most of the calcium and magnesium (75% Mg, 90% Ca). The assessment is more delicate in the case of potassium, for the absorption of this element depends first of all on its concentration in the soil, and it is difficult to ascertain precisely from what level one may talk about "luxury consumption". It will be noted however that 90% of the K is taken up by the straw no matter what the variety. As for nitrogen, we observe important variations which may be due to the type of plant, at least as regards the amounts removed in the vegetative parts; the quantity of nitrogen contained in the grain, which represents more than 50% of the total uptake of this element, being more regular.

d. The level of production

Systematic determinations have been made on sorghum in Upper Volta at different stages of intensification of cultivation (12, 13). Table 5 presents the results obtained in 1969 for 4 levels of intensification (variety S.29, tall-stemmed) applied for 10 years continuous cultivation of sorghum.

		Yield
Stage 1	Control	140 kg/ha
Stage 2	Low rate of unbalanced mineral fertilizer	870 kg/ha
Stage 3	Same rate of mineral fertilizer as stage 2 + 5 t FYM/ha/year	1 800 kg/ha
Stage 4	High rate of mineral fertilizer + 40 t FYM/ha/each two years	3 100 kg/ha

Low rate of mineral fertilizer/ha 8 - 24 - 0
High rate of mineral fertilizer/ha 50 - 50 - 0 (potassium has been included in the formula since 1970)

1 t of FYM at 70% moisture content 7.2 - 3.4 - 15.8
(+ 5.8 CaO and 3.4 MgO)

Table 5 WEIGHT OF UPTAKE FOR A YIELD OF ONE TONNE OF GRAIN
(at approximately 12% moisture content)

Elements / Stages	N			P			K			Ca			Mg		
Uptake	TU	RU	RU TU	TU	RU	RU TU	TU	RU	RU TU	TU	RU	RU TU	TU	RU	RU TU
Stage 1	33.4	14.5	43	4.3	1.4	33	36.8	33.0	90	6.9	6.4	93	6.4	4.7	73
Stage 2	28.4	10.8	38	3.6	1.0	27	31.3	27.2	87	6.9	6.4	92	5.7	4.1	71
Stage 3	33.7	16.0	47	6.4	3.6	56	52.8	48.9	93	7.7	7.1	93	8.0	6.2	78
Stage 4	35.4	16.9	48	7.9	5.0	63	73.8	69.7	95	5.9	5.4	93	6.9	5.2	79

TU: Total uptake
RU: Uptake in aerial residues (stems and leaves)

Inspection of Table 5 shows that the various treatments have little effect on the uptake of nitrogen into stems and leaves. Nitrogen is principally accumulated in the grain and the influence of nitrogen fertilizer on the vegetative organs appeared slight. The level of phosphorus in the latter is relatively low in absolute value, but strongly influenced by fertilization. The effect of the organic fertilizer is particularly clear, no doubt due to the labile form of the organic phosphorus compounds and/or to the action of the manure on liberation and retention of certain forms of soil phosphorus. The amounts of potassium in stems are very important (90% of the K taken up) and vary widely according to the treatments. Calculation of the total uptake in stems and leaves in kg/ha taking into consideration the yields attained demonstrates more clearly the variations according to the level of fertilization (Table 6). It will be noted that the quantity taken up by stems and leaves in the fourth stage of intensification is of the same order of magnitude as the total amount of exchangeable potassium in the 0-20 cm horizon of the soil (0.16 meq/100 g). If one considers the yield of 3 t/ha as realizing the potential of the "soil - rainfall - variety" association, all supplementary addition of mineral elements absorbed by the plant beyond that necessary to obtain these 3 t/ha is recovered in the vegetative parts. This is surely a case of luxury consumption.

Table 6

TOTAL UPTAKE OF K IN STEMS AND LEAVES AND YIELDS AT 4 LEVELS OF FERTILIZATION

	Uptake of K in stems + leaves (kg/ha) per 1 000 kg grain	Grain yield kg/ha	Total uptake in kg K_2O/ha
Stage 1	33.0	140	5.5
Stage 2	27.2	870	28.4
Stage 3	48.9	1 800	105.6
Stage 4	69.7	3 100	259.3

The quantities of Ca and Mg are little influenced by the treatments although, as for potassium, the greater part of these elements is contained in the vegetative organs. K-Ca and K-Mg antagonism is notable only in the 4th stage with a very large organic addition.

Nitrogen is certainly a factor controlling the uptake of other nutrient elements.

The following table shows the variations in quantities of P, K, Ca and Mg in aerial residues of a maize crop at 2 levels of fertilization:

N = 0 (yield 715 kg/ha) local variety
N = 75 (yield 3 450 kg/ha) Jeune de Fo

These results were obtained in a response curve trial on modal weakly ferrallitic soil on sandstone at Farako-Ba.

Table 7

WEIGHT OF UPTAKE FOR A YIELD OF ONE TONNE OF MAIZE GRAIN
(at approximately 13% moisture content - kg/ha)

	P			K			Ca			Mg		
	TU	RU	RU TU	TU	RU	RU TU	TU	RU	RU TU	TU	RU	RU TU
N = 0	22.0	9.0	41	30.7	27.3	89	4.3	3.9	91	11.4	8.8	77
N = 75	10.8	2.5	23	14.3	11.2	78	2.6	1.8	69	4.7	2.6	55
Reference mean with N fertilizer (Senegal, U. Volta, Mali, Niger)	11.4	2.3	23	16.4	8.2	50	3.0	2.2	73	4.8	2.9	60

It is noted that the presence of nitrogen in the fertilizer, prime factor in increasing the production of dry matter, induces a dilution effect. The amounts of P, K, Ca and Mg are clearly smaller at the N 75 level.

The fact that the amount of uptake remains a function of yields, must not, however, be lost sight of. Thus, for the element potassium the total uptake in residues doubles with fertilizer nitrogen in the preceding example.

Dubernard in Cameroon (8) has made an extensive study of the content of mineral elements in the harvest residues of cotton at varying levels of production. A similar study has been carried out at Bouake (9) by separating the components of the harvest residues into two classes: stems + debris (surviving leaves, parasitised capsules, twigs, floral bracts and carpel walls). The results are compiled in Table 8 (17).

The marked change in quantities of potassium with varying yields is noted; variations in the other elements are more limited.

These few results demonstrate that numerous factors, and particularly the level of production, influence the mineral content of aerial residues. They illustrate the difficulty of studies on harvest residues and the danger inherent in the simple extrapolition of data obtained under conditions different from those of the investigation which one is undertaking. Nevertheless, the principal data relating to the main crops is given in the following section, specifying the conditions in which they were obtained, bearing in mind the confidence limits that can be accorded to them.

Table 8

MINERAL ELEMENTS IN HARVEST RESIDUES OF COTTON AT VARIOUS LEVELS OF PRODUCTION

	% CONTENT OF DRY MATTER								
Yield kg/ha	Aerial residues kg/ha		N	S	P	K	Ca	Mg	B ppm
Cameroon									
561	3 120		1.52	0.20	0.16	1.36	0.84	0.28	16.5
1 178	5 900		1.40	0.16	0.20	1.28	0.68	0.26	16.5
1 318	6 500		1.54	0.19	0.22	1.32	0.76	0.28	14.5
1 841	7 400		1.47	0.15	0.20	1.72	0.76	0.28	17.5
2 164	6 800		1.31	0.18	0.20	1.36	0.68	0.24	16.5
Ivory Coast									
773	3 220	stems	0.60	0.08	0.04	0.56	0.68	0.16	12.0
		carp.	0.73	0.23	0.08	2.48	0.44	0.12	13.0
1 489	4 070	stems	0.56	0.04	0.04	1.08	0.68	0.12	13.0
		carp.	0.64	0.24	0.10	2.80	0.44	0.12	14.0
1 645	4 000	stems	0.56	0.04	0.04	1.32	0.68	0.12	13.0
		carp.	0.66	0.27	0.16	3.20	0.44	0.12	14.0

To these difficulties of ascertaining the mineral uptake of different parts of the plant, it is appropriate to add for the sake of completeness those dealing with the problem of sampling. An interesting approach has been taken towards sorghum by J. Gigou (IRAF Cameroon) (13). This study shows that: (a) variability in dry matter weights (necessary for the estimation of total uptake) is always greater than in mineral composition; and (b) variability is greater at the commencement of vegetative growth than at harvest.

ii. Mineral returns under different crops

With these reservations in mind, it is interesting to calculate the quantities of mineral elements in the aerial and underground residues of the main crops. Numerous data are given in the literature and we shall confine ourselves to the principal crops and to two hypotheses: traditional cultivation and improved cultivation.

As regards the food crops, results are cited which were obtained by IRAT and ISRA, Senegal (P. Vidal, L. Jacquinot and C. Charreau) and compiled by F. Ganry (ISRA, Senegal) in a recent paper on the importance of ploughing in of organic matter in the improvement of cropping systems in Senegal (16).

The author urges caution in respect of the estimates relating to the root system, the latter being still imperfectly appraised both quantitatively (variations of 50% in the evaluation of the root mass) and qualitatively.

Traditional cultivation is characterized by low yields with aerial parts removed or burnt after harvest.

Improved cultivation with high yields is distinguished by good development of the root system in proportion to tillage practices and the possibility of ploughing in of aerial crop residues after harvest depending on the duration of the plants and the pedoclimatic conditions.

a. Bulrush millet

Traditional cultivation:

Yield of grain	1 100 kg/ha
Yield of straw	6 200 kg/ha
Weight of roots	800 kg/ha

The straw is entirely removed except for some remnants left behind by men and grazing animals. These residues, estimated at 20%, are burnt before land preparation (Hypothesis I).

In the second hypothesis, the straw remains on the field and is afterwards burnt. In the course of burning, losses of nitrogen and sulphur estimated at 90% of the dry matter occur. The other elements are restored but distributed on the soil in a very uneven manner (burnt in heaps or in strips).

Table 9 RETURNS OF ELEMENTS (kg/ha) - BULRUSH MILLET

		Dry matter	N	P_2O_5	S	K_2O	CaO	MgO
Hypothesis I	Root system Residual straw burnt	800 120	6 1	4 3	1 0.1	9 4	2 7	4 11
	Total return Hypothesis I	920	7	7	1.1	13	9	15
Hypothesis II	Root system Straw burnt	800 620	6 4	4 14	1 0.4	9 16	2 35	4 53
	Total return Hypothesis II	1 420	10	18	1.4	25	37	57

Improved cultivation:

Yield of grain	2 000 kg/ha
Yield of straw	8 000 kg/ha
Weight of roots	1 500 kg/ha

There are three hypotheses for the return of straw:

- the straw remains on the field and is burnt (late-maturing millet, impossibility of ploughing in before the next crop because delayed sowing is detrimental);
- ploughing in with late-maturing millet before sowing (about 30% loss of dry matter);
- ploughing in after harvest if it is a question of a late-maturing millet or in exceptional pedoclimatic conditions.

Table 10 RETURNS OF ELEMENTS (kg/ha) - BULRUSH MILLET

		Dry matter	N	P_2O_5	S	K_2O	CaO	MgO
Hypothesis I	Root system	1 500	11	8	2	17	3	8
	Straw burnt	800	5	18	0.5	21	45	68
	Total return Hypothesis I	2 300	16	26	2.5	38	48	76
Hypothesis II	Root system	1 500	11	8	2	17	3	8
	Straw partially ploughed in	5 600	32	13	3	15	34	48
	Total return Hypothesis II	7 100	43	21	5	32	37	56
Hypothesis III	Root system	1 500	11	8	2	17	3	8
	Straw ploughed in	8 000	46	18	5	21	45	68
	Total return Hypothesis III	9 500	57	26	7	38	48	76

b. Sorghum

Traditional cultivation

Situation A (Upper Volta)	Yield of grain	630 kg/ha
	Yield of straw	5 380 kg/ha
	Weight of roots	590 kg/ha

Results: J. Arrivets (12)

Situation B (Senegal)	Yield of grain	1 100 kg/ha
	Yield of straw	3 500 kg/ha
	Weight of roots	800 kg/ha

L. Jacquinot (10), C. Charreau

The same hypotheses stand as those for bulrush millet.

Table 11

RETURNS OF ELEMENTS (kg/ha) - SORGHUM

			Dry matter	N	P_2O_5	S	K_2O	CaO	MgO
A Upper Volta Centre 630 kg/ha Cycle 125 days Variety S. 29	Hypothesis I	Root system	590	4.5	4.8	-	2.8	0.3	1.5
		Residual straw (20%) burnt	110	0.4	0.5	-	9	0.4	0.7
		Total return Hypothesis I	700	4.9	5.3	-	11.8	0.7	2.2
	Hypothesis II	Root system	590	4.5	4.8 1/	-	2.8	0.3	1.5
		Straw burnt	540	2	2.2	-	44.3 2/	2.0	3.7
		Total return Hypothesis II	1 130	6.5	7.0	-	47.1	2.3	5.2
B Senegal - Saloum 1 100 kg/ha		Root system	800	5	0.5	1	4	2	3
		Residual straw (20%) burnt	70	0.2	0.02	0.2	3	3	5
		Total return Hypothesis I	870	5.2	0.5	1.2	7	5	8
		Root system	800	5	0.5	1	4	2	3
		Straw burnt	350	1	0.1	0.7	12	14	24
		Total return Hypothesis II	1 150	6	0.6	1.7	16	16	27

1/ The value corresponding to the uptake of P_2O_5 in the roots seems very high compared to those obtained in Senegal. This determination was made on the 120th day in Upper Volta and it must be emphasized that the amounts taken up were of the same order of magnitude as those realized in Senegal on the 45th and on the 75th day, namely 0.7 kg P_2O_5. Arrivets believes that from the 90th day there is a significant migration of P_2O_5 towards the roots.

2/ The amounts of K_2O taken up are of the same magnitude, the maximum being reached by the 75th day. Arrivets considers that losses by root excretion and rainwash are relatively high.

<u>Improved cultivation:</u> Yield of grain 2 500 kg/ha
Yield of straw 7 500 kg/ha
Weight of roots 2 000 kg/ha

Table 12 RETURNS OF ELEMENTS (kg/ha) – SORGHUM

		Dry matter	N	P_2O_5	S	K_2O	CaO	MgO
Hypothesis I	Root system	2 000	12	1	2	9	5	9
	Straw burnt	759	2	3	1.5	25	29	52
	Total return Hypothesis I	2 750	15	4	3.5	34	34	61
Hypothesis II	Root system	2 000	12	1	2	9	5	9
	Straw ploughed in	7 500	26	3	15	25	29	62
	Total return Hypothesis II	9 500	38	4	17	34	34	71

For the above two traditional cereals, the varieties of which are most frequently short-term, it is difficult if not impossible to plough in after the harvest. A different form of return is to be expected with preparation and ploughing in of manure or compost according to the presence or not of animals on the farm.

c. Maize

These results were obtained under improved rainfed cultivation and were recorded in a nitrogen response curve experiment on modal weakly ferrallitic soil at Farako-Ba (IRAT, Upper Volta) and are limited to the aerial parts. The levels of P_2O_5 and K_2O fertilizer were respectively 190 kg/ha and 50 kg/ha. The data correspond to the mean of results recorded on plots which had received 50 and 75 kg of nitrogen (results by Dupont de Dunechin (11).

The two hypotheses are:

- Removal of straw for fodder with delayed recycling (farmyard manure) and burning of residual straw (18);
- All residues ploughed in at the end of the growing period.

Yield: 3 050 kg/ha maize grain at 21% moisture content.

Table 13 RETURNS OF ELEMENTS (kg/ha) – MAIZE

		Dry matter	N	P_2O_5	K_2O	CaO	MgO
Hypothesis I	Residual straw burnt	400	0.3	0.5	5.6	0.9	1.0
Hypothesis II	Residues ploughed in	2 300	11.8	2.6	28.0	4.7	4.9

The results are markedly inferior to those obtained in Senegal or in temperate climates as far as nitrogen and phosphorus are concerned. It may be that the short-term local variety used has a lower requirement for these elements.

d. Groundnuts

There are two hypotheses according to F. Ganry (16):

Traditional cultivation:

Traditional cultivation:	Yield of pods	1 200 kg/ha
	Weight of fallen leaves	700 kg/ha
	Weight of roots	600 kg/ha

The aerial parts are entirely removed for fodder, even though there is significant defoliation of around 25%.

Table 14 RETURNS OF ELEMENTS (kg/ha) - GROUNDNUTS

	Dry matter	N	P_2O_5	S	K_2O	CaO	MgO
Root system	600	10	1	1	6	7	7
Leaves (1/4 fallen leaves)	175	4	1	0.5	5	4	3

iii. Improved cultivation:

Improved cultivation:	Yield of pods	2 250 kg/ha
	Weight of fallen leaves	3 100 kg/ha
	Weight of roots	1 000 kg/ha

The dead leaves are also removed, but by reason of the good harvesting and shelling conditions, the losses by defoliation are reduced to 10%.

Table 15 RETURNS OF ELEMENTS (kg/ha) - GROUNDNUTS

	Dry matter	N	P_2O_5	S	K_2O	CaO	MgO
Root system	1 000	16	2	2	10	12	12
Leaves (1/10 fallen leaves)	310	3	1	0.5	4	3	3

Cowpeas (Vigna unguiculata) are cultivated under the same conditions as groundnuts (removal of the dead leaves for fodder). The amounts removed are similar, but clearly richer in potassium (45 kg K_2O taken up for a yield of one tonne of seeds). There is, therefore, reason to be cautious in the case of intensive sole cropping, for there are strong chances of potassium deficiency appearing in the absence of a complete NPK fertilizer (17).

a. Cotton

The harvest residues consist of roots, stems, branches, leaves, floral bracts, carpel walls, mummified capsules. The large variations in yields have already been stressed. Deat and Sement (15) mention that the aerial residues, in the case of the variety 444-2, represent 69% of the total weight of the aerial production for a yield of 770 kg/ha, but only 48% for a yield of 2 150 kg/ha. These aerial residues are for phytosanitary reasons and/or picking methods, piled in heaps and burnt and this action causes the greater part of the elements N and S, which they contain, to be lost by oxidation.

By adopting the data obtained by Dubernard in Cameroon in 1972, three hypotheses can be considered:

Hypothesis I	Stems and dry leaves burnt in the course of the dry season Yield of seed cotton - 800 kg/ha Stems and leaves - 3 000 kg/ha
Hypothesis II	Stems and dry leaves burnt in the course of the dry season Yield of seed cotton - 1 600 kg/ha Stems and leaves - 6 000 kg/ha
Hypothesis III	Mechanized cultivation: Preliminary rotavation and incorporation of residues at the beginning of the rainy season Same production as for Hypothesis II

In these three hypotheses, it is conceded that the dry leaves dropped onto the soil after the significant defoliation, occurring in the course of successive harvests, are also burnt or ploughed in. The figures for aerial parts in place are therefore probably overestimates.

The table shows the importance of returns in the case where ploughing in of residues is substituted for simple burning and the important contribution of the roots.

b. Upland rice

Four hypotheses may be considered:

Hypothesis I	Traditional cultivation - yield: 1 000 kg/ha Harvesting by hand - heads cut along with part of the stem 70% harvest residues burnt
Hypothesis II	Improved cultivation - yield 2 500 kg/ha 90% straw burnt after mechanical harvesting
Hypothesis III	Yield: 2 500 kg/ha 90% straw mechanically incorporated after harvest rotavated
Hypothesis IV	Yield: 2 500 kg/ha Straw removed for fodder, an estimated 20% of residues ploughed in.

Table 16 RETURNS OF ELEMENTS (kg/ha) - GROUNDNUTS

		Dry matter	N	P_2O_5	S	K_2O	CaO	MgO
Hypothesis I 800 kg/ha	Root system	600	6	3	1	8	4	3
	Stems, leaves + carp. walls	300	5	15	0.6	57	32	15
	Total return Hypothesis I	900	11	18	1.6	65	36	18
Hypothesis II 1600 kg/ha	Root system	1 200	12	6	1	16	8	6
	Stems, leaves + carp. walls	600	10	30	1.2	114	16	12
	Total return Hypothesis II	1 800	22	36	2.2	130	24	18
Hypothesis III 1600 kg/ha	Root system	1 200	12	6	1	16	8	6
	Stems, leaves + carp. walls	6 000	96	30	12	114	16	12
	Total return Hypothesis III	7 200	108	36	13	130	24	18

Table 17 RETURNS OF ELEMENTS (kg/ha)
(AERIAL PARTS ONLY)

	N	P_2O_5	K_2O	CaO	MgO
Hypothesis I	0.8	3.5	21	6.3	2.1
Hypothesis II	2.5	11	68	20.2	6.8
Hypothesis III	25	11	68	20.2	6.8
Hypothesis IV	5.5	2.5	15	4.5	1.5

c. Fallow (wild ley)

It is interesting to mention the returns under fallow, the latter sometimes being included in cropping systems. Very precise data have been collected in Senegal (16–18). Two hypotheses can be considered:

Hypothesis I — Traditional system (1 or 2 years of fallow)
With production of hay at the end of the rainy season and burning in the dry season.
Hay: 2 000 kg/ha
Weight of roots: 700 kg/ha

Hypothesis II — Improved system
Straw ploughed in at the end of the rains
Straw: 5 000 kg/ha dry matter
Weight of roots: 1 700 kg/ha dry matter

Table 18 RETURNS OF ELEMENTS (kg/ha) – FALLOW (WILD LEY)

	Dry matter	N	P_2O_5	K_2O	CaO	MgO	S
Root system Straw burnt	700 200	4 2	1.5 8	12 30	2 18	1 9	0.7 0.2
Total return Hypothesis I	900	6	9.5	42	20	10	0.9
Root system Straw ploughed in	1 700 5 000	10 40	3 20	29 75	5 46	3 22	2 6
Total return Hypothesis II	6 700	50	23	104	51	25	8

1.1.5 Conclusion

If we have dwelt at length on the mineral aspect of crop residues, it is because this is often played down in comparison with the strictly organic aspect. In our view and considering the difficulties experienced at this juncture (very high cost/price ratio), a rational utilization of crop residues in different ways chosen according to the level of technology of the farmer may enable an approximate mineral balance and the satisfaction of socio-economic criteria.

Burning, when there are no other solutions available, must not be condemned outright. We have seen that for all crops, it allows the recycling of phosphorus, calcium and magnesium and above all of potassium, the amount of which in vegatative organs is very important. Of course, as often as possible, ploughing in or return in the form of compost and farmyard manure is preferable. The latter practices in particular conserve nitrogen and sulphur. Nitrogen is an expensive element. After correction of phosphate deficiency (which is relatively easy with local materials), it is most frequently the key element in fertilization of cereals.

A cursory inspection of the preceding tables shows us that ploughing in the aerial residues of a cotton crop, which produced 1 600 kg/ha of seed cotton, is equivalent to 108 kg/ha nitrogen while burning results in the return of only 22 kg/ha. Can it be doubted that at least a part of this nitrogen, stored in the soil and liberated progressively and proportionately as the plant material is broken down by micro-organisms, will not have some effect on the following cereal and at least in the medium term on the organic status and mineral balance of the soil?

It is appropriate to examine now the organic aspect of the problem of crop residues, endeavouring to separate their long term and short term effects on soil fertility.

1.2 Crop Residues: Source of Organic Matter - Long Term Effect - Balance

It is more difficult to quantify the contribution of crop residues to the organic matter. It is important to recall that the increased use of mineral fertilizers, with a view to better yields, leads to an increased production of vegetative residues (roots and aerial parts).

1.2.1 Organic return of crops

The following table presents estimates of the quantities of dry matter, carbon and nitrogen contained in the aerial residues and roots of the main crops according to the hypothesis set up in section 1.1.4 - ii - a.

It will be noted that in systems in which burning of straw is the rule, the roots alone contribute to the formation of organic matter - carbon and nitrogen in the aerial parts being entirely lost by fire. The practice of burning is thus extremely detrimental to the organic balance of soils.

1.2.2 The general effects of organic matter

Drouineau (19) distinguishes between short and long-term effects as follows.

The short term effects of crop residues (transformed or not) take place in a limited interval of time (a few weeks to a few months) and will influence the yield of the subsequent crop. It is in general this type of effect which is observed and measured in field experiments. They are most often due to the "not yet humified" fraction of soil organic matter. It should be noted that it is often difficult to provide evidence for the specific organic matter effect, for in the prevailing conditions of poor tropical soils the mineral effect is often overriding.

The long term effects refer essentially to the maintenance of the organic content of the soil at a satisfactory level. The question is to find out at what level the soil organic matter must be maintained in order to extract the best part of the mineral nutrients without reductions in the capital of fertility. These effects are due to stable substances complexed to clay particles, generally called "humus", and also to labile fractions (the effects of which are renewed where fresh organic matter is regularly applied) susceptible moreover to rapid alteration into the bound forms if conditions are favourable.

It is one of the major contributions of the work of G. Monnier (20) to have shown that the turnover or dynamic aspect of organic matter is much more important than the simple quantitative aspects.

Table 19 RETURNS OF DRY MATTER, CARBON AND NITROGEN IN CROP RESIDUES (kg/ha)

Crop	Economic yield	Treatment of residues	Dry matter weight		Roots		Aerial parts		Total	
			Roots	Aerial parts	C	N	C	N	C	N
Millet	1 100	Removed – 20% res. burnt	800	120	360	6	55	1	415	7
	1 100	Burnt	800	620	360	6	280	4	640	10
	2 000	Burnt	1500	800	675	11	360	5	1035	16
	2 000	Ploughed in (70%)	1500	5600	675	11	2520	32	3195	43
	2 000	Ploughed in after harvest	1500	8000	675	11	3600	46	4275	57
Sorghum	630	Removed – 20% burnt	590	110	270	4.5	50	0.4	320	4.9
	630	Burnt	590	540	270	4.5	240	2	510	6.5
	1 100	Removed – 20% burnt	800	70	360	5	30	0.2	390	5.2
	1 100	Burnt	800	350	360	5	160	1	520	6
	2 500	Burnt	2000	750	900	12	340	3	1240	15
	2 500	Ploughed in	2000	7500	900	12	3380	26	4280	38
Maize	3 050	Burnt	1500	460	675	12	210	0.3	885	12.3
	3 050	Ploughed in	1500	2300	675	12	1035	11.8	1710	23.8
Ground-nuts	1 200	Removed	600	425	270	10	350	4	620	14
	2 250	Removed	1000	300	450	16	140	3	590	19
Cotton	800	Burnt	600	300	270	6	140	5	410	11
	1 600	Burnt	1200	600	540	12	280	10	820	22
	1 600	Ploughed in	1200	6000	540	12	2800	96	3340	108
Upland rice	1 000	70% burnt	600	105	270	4	50	0.8	320	4.8
	2 500	90% burnt	1600	340	720	12	150	2.5	870	14.5
	2 500	90% ploughed in	1600	3300	720	12	1480	25	2200	37
	2 500	Removed – 20% ploughed	1600	750	720	12	340	5.5	1060	17.5
Fallow	2 000 kg hay	Burnt	700	200	315	4	765	2	1080	6
	5 000 kg hay	Ploughed in	1700	5000	765	10	2500	40	3265	50
Cowpeas	1 000	Removed	500	400	225	9	180	6	405	15

1.2.3 The principal functions and effects of organic matter in tropical soils

A brief review follows of the principal long term functions and effects of organic matter, bearing in mind that crop residues make an important contribution to its status.

i. Influence on the nutrition and growth of plants

It has been shown that organic matter has a direct effect on the nutrition and growth of plants. The elements stored in humus are labile and easily available for the nourishment of plants, either directly by simple solution as in the case of potassium particularly or progressively in proportion to the microbial breakdown of fresh organic materials. Humus likewise plays an important role vis-a-vis phosphate nutrition (21). The nitrogen nutrition of plants from organic matter depends on the pedoclimatic conditions.

In Senegal on sandy soil, Blondel (22) and Ganry observe, in conditions of sufficient rainfall, a distinct peak of mineralization right at the beginning of the wet season. This peak is followed by a phase of mineralization at a very low level during the rainy season. This fact argues in favour of early planting. In conditions of deficient rainfall, the peak is not visible and a higher plateau of mineralization throughout the season is observed.

The above authors have shown important differences among soil types.

ii. Importance of humus in the exchange complex

Humus is one of the prime factors controlling the equilibrium between adsorbed and dissolved ions in the soil. The exchange capacity of soils is related to the nature of the exchange complex and the presence of humus in greater quantity considerably increases the possibilities of storage of mineral elements.

In Senegal, J.F. Poulain (23) has determined separately the mineral and organic exchange capacity of a Dior soil under two treatments of long duration: (a) long term fallow (10 years); and (b) cultivation of groundnuts (5 years).

The following results were obtained for an exchange complex consisting of:

Clay 4% (60% kaolinite, 10% montmorillonite + iron hydroxides)
Organic matter C‰ 2.6 (fallow) to 2.1 (groundnuts)
N‰ 0.25 (fallow to 0.20 (groundnuts).

The importance of the organic component is established in spite of the small quantities observed in this type of soil.

	FALLOW	GROUNDNUTS	
CEC mineral	2.11	2.25	
CEC organic	1.07	0.65	in meq/100 g
TOTAL	3.18	2.90	

iii. Physiological role

Organic matter plays an important role in the solubilization and chelation of iron, thus avoiding chlorosis.

iv. Water-holding capacity

Humus, by its property of wettability, affects the water-retention capacity of soils.

In a study of light soils of Senegal, R. Maignien (24) has clearly shown the influence of humus on the water retention capacity.

Water retention capacity:	12	12.5	18.5	24.5
Humus %:	0.27	0.31	0.45	1.05

Ganry (16) notes that the more residues are transformed, the more water they absorb and cites by way of example:

Straw: 250 to 260 kg per 100 kg
Farmyard Manure: 800 to 850 kg per 100 kg

G. Aubert has shown the great affinity for water of slightly acid humus in ferruginous tropical soils.

v. Structure and root development

The ability of humus to form aggregates has been amply demonstrated. This tendency to form stable aggregates by coating and cementation allows:

- the creation of structure in sandy soil
- the correction of defective nature of clay in heavy soils

R. Nicou (25) has shown that the ploughing in of fresh plant material (of sufficiently low C/N ratio) has an immediate action in lessening compaction on drying. In a comparison of more and more humified forms - green manure, straw, compost and farmyard manure, the author observed that their action on cohesion diminishes and may even be reversed. He was able to establish a close relation between the quantities of primary products of decomposition (polysaccharides) and the loss of cohesion and was led to recommend the constant presence of fresh organic materials in order to reduce compaction.

Another interesting effect concerns porosity which is considerably increased in the presence of organic matter. This property allows on the one hand better moisture storage and on the other hand denser and deeper development of the root system with consequences on the water and mineral nutrition of crops and protection against erosion and runoff.

vi. Provision of nutritive substances for micro-organisms

Organic matter returns are necessary for the microbial life of the soil. Ganry points out that in the case of farmyard manure it is rather a question of activation of the micro-organisms present in the soil by addition of nutrients and energy sources than a simple inoculation.

vii. Indirect influence - Specific substances

It was shown a long time ago (Flaig - Chisterva) that the presence of certain substances which appear in the course of transformation of organic matter may play a specific physiological role. Certain quinones and benzo-quinones might increase the absorption capacity and length of roots. Other substances by contrast have an inhibitory role in growth, such as those liberated by the decomposition of sorghum residues (roots and stems), which would explain the depressive effect of ploughing in on the succeeding crop. Chaminade and Blanchet put forward the hypothesis that these actions were related to a change in permeability of the cell wall.

viii. Resistance to certain pests and diseases

Organic materials may play a role against root diseases, but contrary observations have been noted with little humified plant material (termites in particular).

1.2.4 Variations in organic matter with time

It is essential to know the turnover of organic matter in the soil and what are the models capable of representing this turnover. The equation presented here supposes that the variation in the quantity of organic matter in a given interval of time is equal to the difference between the quantity of organic matter added per unit of time (cropping season for example) A and the quantity of organic matter which disappears during the same time interval. This quantity is proportional to the mass of organic matter (H) multiplied by a proportionality factor which represents the rate of decomposition (k).

$$\frac{dH}{dt} = A - kH$$

H, A, k are measured in the same depth of soil

In defining the balance, two elements are particularly interesting.

The isohumic coefficient: that is to say the fraction of labile organic matter being transformed into stable humus. For the principal forms of organic matter added, we may accept the following values:

Decomposed manure	0.5 to 0.3
Farmyard manure	0.3 to 0.2
Straw	0.15 to 0.08
Green material (fresh green manure)	c.0

These values are, however, approximate because significant variations depending on pedoclimatic conditions, husbandry practices and the inorganic fertilizer regime can be anticipated.

The decomposition constant (k): in temperate countries 0.8 to 1.2% of the humus present in the soil is decomposed, but the percentage is larger in tropical regions. In Senegal, Siband and Charreau (26) give estimates of k ranging between 2 and 9%.

The parameter k may be expressed in terms of carbon or nitrogen. In the latter case, it is important to point out that for each type of organic manure there exists an apparent rate of loss of nitrogen, independent of the quantities of organic matter introduced. Moreover, this rate is higher when the organic matter regularly applied consists of humified compounds (farmyard manure - compost). When the fertilizer is entirely inorganic, the rate of turnover is reduced, especially when a high level of nitrogen is added to the soil.

The seasonal addition of organic matter (A) may be expressed in the form of nitrogen or carbon. Nitrogen is the better choice, being the prime factor limiting the formation of humus. Some estimates are included in Table 19. They enable the calculation of annual additions and show the harmful influence of burning, the consequence of which is the low quantity of organic matter and humus in cultivated tropical soils, estimated (according to Cointepas (28), Charreau and Vidal (29) and Poulain (23) at 10 to 25 t/ha.

The quasi-mathematical model presented is clearly attractive, but it represents only an approximation for it remains difficult to define the level of organic manure necessary to maintain the humic balance at equilibrium. The contribution of crop residues may be considerable, but it is important to define simultaneously the inorganic fertilizer regime which regulates its volume.

In the following section, the principal sources of organic matter are reviewed.

2. THE PRINCIPAL SOURCES OF ORGANIC MATTER FROM CROP RESIDUES

2.1 Limits of Organic Manuring Alone

In exclusively organic fertilization, it is necessary to distinguish between returns from a standing crop and returns from elsewhere which result in transfer of fertility.

Without additions from elsewhere, uptake of nutrients in vegetative parts + Amounts removed in the harvest + Various losses (runoff, erosion, leaching) > Return of nutrients in harvest residues (stems, leaves, roots).

Thus, Ganry (16) was able to calculate that, in the absence of sufficient inorganic fertilizer and adopting a system of 50% return (which is perhaps optimistic), the present average production of 1 000 000 t of groundnuts and 750 000 t of cereals, such as millet, withdraws from the basic heritage of Senegal each year more than 200 000 t of nutrients and 25 000 t of lime.

Although it is not claimed that organic matter by itself can solve the problem of the mineral deficit, all the sources of organic matter must nevertheless be preserved.

2.2 The Sources of Organic Matter

Different forms are at the disposal of the farmer:

- Some lignified green material: green manure - green fallow
- Crop residues in the true sense: cereal straw, cotton stems, etc.
- Compost
- Manure

Apart from manure, not available on farms without cattle, it is usual to look for substitutes. The first and least costly that can be thought of are the harvest residues whose importance was appraised in the preceding section. It was seen that the amounts of organic materials that it can be hoped to obtain are relatively large, provided burning is avoided, and that their mineral effect is very important in the upgrading of a cropping system.

The systematic study of the ploughing in of green material (fallow, green manure, forage regrowth) has been carried out for many years in tropical Africa and important findings are available on this subject (in particular the work of R. Tourte and co-workers at CRA, Bambey since 1949). The mass of dry matter produced in place varies according to the species, the climatic conditions and the duration of the vegetation.

A certain number of obstacles have been put forward. In the first place, ploughing in requires traction power which may be lacking. Next, the need for increased yields which goes step by step with population growth is expressed in an expansion of cultivation at the expense of non-productive areas in the rotation (or considered as such) - fallow, green manure ...

Some not very convincing results, due in most cases to poor experimental conditions, have also been recorded on short cycle rotations. One would think, however, that the development of fodder production would enable, after mowing or direct grazing, the ploughing in or regrowth in the form of green material at the end of the growing period.

One of the characteristics of these green materials is their rapidity of fermentation (low content of humus precursors). This high rate of decomposition and the low value of the C/N ratio engender only a very small increase in the humus content, but the beneficial effect of these substances on certain soil properties has been demonstrated.

There is, moreover, no exclusive solution and additions at the level of the cropping system of green material and crop residues would give grounds for hope for an equilibration of the humic balance and favourable consequences on the physical properties of the soil.

Compost and cattle manure permit the concentration of organic matter (34):

- concentration <u>in space</u> by transporting to the arable fields all the organic resources of the farm (generally with transfer of fertility when the farm comprises pasture and special plots receiving compost and manure);
- concentration <u>in time</u> because it appears more practical to apply manure or compost to a few demanding crops in the rotation;
- finally, concentration <u>in mass</u> because these stable products concentrate organic matter and mineral elements.

These advantages are unfortunately counterbalanced by a much increased labour cost. Moreover, the losses are probably important and the quality of the product often mediocre.

3. HARVEST RESIDUES IN TRADITIONAL PRODUCTION SYSTEMS

Each individual holding practises a production system peculiar to itself. However, in order to better understand the importance of crop residues on the farm it is necessary to propose a classification of the traditional systems according to some criteria. To simplify the problem, they have deliberately been limited to two, these being in our view fundamental:

i. presence or absence of cattle (especially oxen) as a vital part of the farm;

ii. presence or absence of land available for regeneration or forage outside the arable land.

3.1 Livestock Rearing

Omitting the commercial and potentially intensive types of cattle raising, which are still of negligible importance, we can distinguish two types of livestock rearing which co-exist in the Sudano-Sahelian zone:

- extensive pastoralism of the Sahelian or Sudanian type;
- small-scale mixed farming (peasant agriculture) which may evolve into a subsistence or cash economy.

Unfortunately, it must be admitted that the reality is quite different and that traditional livestock rearing is adapted to the conditions of the environment in which it exists.

In the Sahelian zone, it is of an extensive and semi-nomadic character. The herds are continually on the move in search of grazing and water according to the alternation of the seasons.

By contrast, in the Sudanian zone of sedentary cultivation, the animals co-exist with the farmers without real integration.

Livestock rearing is more important in the former zone with, however, changes in management and a tendency towards settling by part of the pastoral family, which may have been established in this zone for one or several generations. Crops accordingly assume an increasing importance and the amplitude of transhumance is diminishing.

The second type of livestock rearing, represented by the herds belonging to the sedentary cultivators, shows different characteristics. Several variations are practised:

i. In general the farmer entrusts his cattle to a herdsman who takes charge of them in addition to his own herd. Sometimes, the farmer or a village commnunity entrusts the care of the herd to a salaried herdsman or to a group of children. There is thus an association between stock-keepers and cultivators and one imagines that the system poses as a priority the problem of management of the territory in the sense of a symbiosis and not of a segregation.

ii. Real integration between cultivation and cattle raising implies the establishment of a rotation with fallows for fodder and the rational utilization of all the by-products of cropping. The progressive peasant, associated or not with oxen traction, is a very promising form but as yet poorly represented no doubt for want of public support. The importance of small ruminants likewise imposes on this model the complete utilization of all crop residues.

As soon as there is a genuine integration between cultivation and cattle raising, all the harvest residues are reserved for the animals.

An example is cited from farms coming under the Management Authority of the Volta Valley (Upper Volta) where the rotation practised by the farmers is:

Fallow	1.25 ha
Fallow	1.25 ha
Millet – Sorghum	0.65 ha / 0.65 ha
Cotton	1.25 ha
Groundnuts – Cowpeas	0.65 ha / 0.65 ha
Sorghum – Maize – Rice	0.25 ha / 0.50 / 0.50 ha

The production of fodder calculated over 6 ha of crops and 2.5 ha of fallow for an average family unit of 4 active persons is:

2 ha	Millet – Sorghum Maize	3.0 t fodder
0.65 ha	Cowpeas	1.5 t
0.65 ha	Groundnuts	0.5 t
0.5 ha	Rice	0.3 t
2.5 ha	Fallow	3.8 t
		9.1 t

while one pair of oxen requires a minimum of 8.25 tons of dry fodder per year.

It is evident that the family holding described above can maintain one pair of oxen, but as it seems desirable to have at least two pairs, it must be admitted that the fodder produced on the farm must be entirely reserved for grazing, supplemented by pasture, situated outside the cultivated blocks. This problem is very important and shows that any production system based on oxdrawn cultivation runs the risk of failing unless the policy for feeding the animals is clearly defined.

The presence of animals on the farm, while it imposes constraints from the point of view of feeding, does allow the farmer to solve the problems of transport (straw, water) and to envisage the transformation of harvest residues into more elaborate products (compost and farmyard manure), but this intensification is as yet scarcely perceptible in the present systems, or only in very localized zones (Centre of Mali – some places in Senegal).

3.2 Cropping Systems

3.2.1 Traditional systems – Shifting cultivation

In the original traditional systems of the tropical zone, long bush fallows could be observed which interrupted the cropping cycle. Shifting cultivation, in the strict sense, accompanied by a slow migration of the population is now rarely seen; instead, permanent villages can be found and a succession of crops in space (nearly always food crops) alternating with long bush fallows.

This practice is still common and the example of middle Baoule (Ivory Coast) is given, where the system is as follows:

1st year – An area of forest or fallow is cleared in the dry season with a matchete. Rapid drying – burning. The small extent of the area limits runoff. Large shrubs are allowed to stand and serve to support climbing yams.

– Manual preparation of the soil with the digging-stick. Superficial cultivation and making of mounds for yams. Mounding is the only tillage operation of the Baoulian peasant.

- Propagation by slips just at the time of the first heavy rains. Sowing of maize and spice plants between the rows (mixed cropping).

2nd year - Superficial cultivation of eroded parts of the mounds. Phased planting of different varieties of rice or groundnuts.

The plot is abandoned and eventually returns to the natural vegetation. Le Buanec (33) pointed out that abandonment of the plots is not due to exhaustion of the soil but to invasion by weeds.

This system calls for large areas with very limited exploitation. It is still found in certain regions of West Africa where land is plentiful.

Barral (31) also cites the Tiago country (Tenado circle in Upper Volta) where cultivation is divided into three quite distinct zones:

- concentric circles of permanent and simi-permanent fields around the family homesteads, the nearest fields being fertilized with household refuse and farmyard manure prepared by small stock; the outer circle generally cropped to red sorghum does not receive any fertilizer;

- an intermediate band about 100 m wide supporting bushy vegetation or pasture for sheep and goats;

- a zone of bush and extensive shifting cultivation. These fields are cropped to white sorghum for a miximum of 8 years and then abandoned to a long fallow of fifteen to twenty years.

In Dagari country (Leo circle) one finds an analogous situation with fields around the homestead, regularly fertilized, next a ring of fields under semi-permanent cultivation with short fallows, lastly a broad zone of bush and shifting cultivation with fields cultivated continuously for 6 to 7 years and afterwards abandoned to a very long fallow of sometimes 30 or 40 years.

These systems, made possible by a plentiful supply of land are, however, destined to disappear by reason of population expansion and their very low productivity. Still, equilibrium is maintained thanks to the transfer of fertility from distant fields to fields around the homestead and to the existence of very long bush fallows following a few years of continuous cropping in the outer zone.

3.2.2 Semi-permanent cultivation systems

These systems are still numerous in tropical Africa. They have generally evolved from the previous system under the influence of population pressure and the expansion of cash cropping. In fact, in certain zones there are tracts of land uncultivated for many years. The appearance of the herbaceous vegetation and the absence of trees leads one to think that their regeneration is hypothetical. The farmer, in order to ensure his own subsistence, is thus forced to adopt a system of short-term fallows alternating with cropping.

An example can be cited from the landuse system of the Serere in Senegal: the system comprises a typically triennial rotation and the integration of cropping with cattle rearing and fodder trees. The herd is folded during the cropping season in one field enclosed by a thornbush hedge. Immediately after harvest, the hedge is opened and the cattle take advantage of fodder provided by numerous Acacia albida trees. The next field carries millet which benefits from the soil improvement brought about under the preceding crop (groundnuts). The last field carries groundnuts. Around the village, one finds permanent fields of millet, cowpeas and spice crops fertilized with household refuse.

These systems are becoming fragile. Intensification could be envisag if the fallows were rationally exploited by ploughing under at the end of th growing period, but such is not the case and because of population pressure, subsistence requirements and mediocre yields, the fallows are destined to disappear, to give place in the medium term to systems of intensive cultivat without hope of regeneration.

3.2.3 Systems of continuous cultivation

In certain regions it is clear that each year the area under fallow i diminishing.

In Upper Volta, it is now common to come across farms where the entir area is cultivated. What is more disturbing is that continuous monoculture of sorghum or millet is often the rule and that the return of crop residues is limited to the root system and a small percentage of the aerial parts bur before land preparation.

The agronomist must manifest his concern in the face of such a system which, although enabling the maintenance of yields at a very low level, compromises the future by systematically exhausting the mineral and organic reserves of the soil.

The permanent character of the cultivation with total occupation of the land area is not, in these conditions, a criterion of intensification in the absence of techniques whose cost seems at present to put them out of reach of the peasant farmer.

4. PROPOSALS FOR THE UTILIZATION OF CROP RESIDUES IN TRADITIONAL CROPPING SYSTEMS

The distinction between systems with and without cattle is fundamental for the utilization of crop residues. On the other hand, the latter must be the more recommended where idle land is limited or even nonexistent.

4.1 Farms with Cattle

On farms where cattle are present, there are various possibilities:

- preparation of farmyard manure,
- ploughing in of residues (ox-ploughing),
- transport of straw for composting on the field or near the homestead, etc.

Solutions which call for burning must be denounced. The greater part of the harvest residues, if not the whole, must be reserved for feeding the animals.

In these conditions there must be deliberate orientation towards the rationa preparation of farmyard manure with stable litter (transport being available) and the ploughing in of residues not consumed. Ploughing in should be done at the end of the growing period immediately after the cereal straw has been removed. The latter may be removed entire or chopped up so as to facilitate transport and storag At the beginning of the season, as soon as the first rains have provided good conditions for tillage, the residues not consumed cen easily be turned under. Transfe of fertility may be avoided by establishing a regular timetable of organic addition to all the fields on the farm.

4.2 Farms Without Cattle

On farms without cattle the possibilities are more restricted but the need for return of organic matter more imperative. The application of mulch or straw with consequent transfer of fertility is a possibility. In the Ouahigouya zone of Upper Volta, the application of straw begins in February and is carried out not only with harvest residues but also with wild plants which the farmers go to collect, sometimes from a great distance. The straw is spread on the soil in a relatively thin layer held down by stones. This practice has resulted in the complete disappearance of burning of millet stems after harvest and bush fires. The seed is sown in pockets across the straw on untilled soil.

Composting is equally possible but since transport is by hand or by donkey cart, long distances are excluded. Composting can be done directly on the field with utilization of the compost after one rainy season.

4.3 Need for Integration Between Agriculture and Livestock Rearing

The limitations of a farm without cattle are evident and show to what extent ox-drawn cultivation must remain a top priority in the objectives of extension. The effects of the latter are often much delayed, but some examples (San-Segou region in Mali) demonstrate that important and irreversible results may sometimes be attained after one or two decades.

In the first stage, extension must persuade the farmer to use animals for simple jobs. The cart may be viewed as an important means of incentive. The animals must be housed overnight and during the heat of the day in a simple shelter in which the preparation of farmyard manure with the addition of litter can be envisaged. Real integration of agriculture and cattle rearing no doubt corresponds to a high level of technology for the peasant. The regular stabling of cattle would thus enable an almost complete recycling of the crop residues of the farm. It is a pity that even in conditions where the presence of cattle would allow it, the transport constraint means that harvest residues are rarely used in the preparation of manures, the former being considered only suitable for grazing.

4.4 Motorization

In certain situations, recycling of harvest residues, and hence maintenance of fertility could be a positive fact, but only by the introduction of motorization (or semi-motorization), which would enable:

- preparation of the material to be incorporated (rotavated);
- homogeneous incorporation of the material so prepared free from the pressure of time.

The problem becomes in that case an economic one, but it cannot be solved by considering only the short term costs and benefits.

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Paper 3

CROP RESIDUE MANAGEMENT IN RELATION TO TILLAGE TECHNIQUES FOR SOIL AND WATER CONSERVATION

R. Lal [1]

1. INTRODUCTION

Seed bed preparation is carried out for both short term and long term objectives. The immediate purpose is to optimize soil temperature and soil moisture regimes in the seedling zone, minimizing weed competition, stimulate root system proliferation and development, and decrease the peak labour demand. However, in the long run, a system of seed bed preparation should maintain soil productivity indefinitely through: adequate soil and water conservation, by maintaining soil organic matter content, preserve soil structure and pore stability, and improve water and nutrient retention capacity of the soil.

Successful introduction of large scale mechanized arable farming in the humid tropics of Africa is possible only if these short and long term objectives of "tillage" or seed bed preparation are fulfilled. The distinction between "exploitation" of the limited and to some extent "perishable" land resources in favour of short term production gains, compared with "developing" land resources considering ecological constraints with the objective of continuous and sustained production is a vital issue for decision makers and planners.

Important ecological constraints include high climatic erosivity of the humid tropics (Hudson 1976; Lal 1976; Roose 1973), low tolerable limits of soil erosion in this region (Lal 1976), high rate of mineralization of soil organic matter content, low nutrient and water holding capacity of the soil and poor root penetrability due to unfavourable soil physical and chemical characteristics. Failures to recognize the importance of these ecological constraints by planners and decision makers prior to undertaking large-scale land development schemes in the tropics of Africa, have led to large tracts of barren and unproductive lands where lush forest once prevailed (FAO 1974).

This problem no doubt is complex, but should be tackled with the understanding of ecological principles. If an ecological imbalance is created, the consequences can be disastrous in terms of irreversible soil degradation by erosion.

2. PRINCIPLES OF SOIL CONSERVATION

Soil detachment, caused by rain drop impact on bare ground, and the sealing of the soil surface resulting in low water intake rate constitute the initial steps in accelerated soil erosion on land cleared of its forest vegetation cover. Forest vegetation cover is an energy breaker and protects the soil against this "beating" action of tropical rains. Median drop size (D_{50}) of 3 mm is not uncommon in the tropics (Aina <u>et al.</u> 1976; Kowal and Kassam 1977). As a consequence of high drop size, intensities of 150 mm/ha or more at the beginning of the rainy season cause serious damage to soil structure and accelerate soil erosion.

If the role of forest canopy as an energy breaker can be fulfilled by an equivalent cover, there will be minimum soil detachment. Hudson (1976) reports that over a period of 10 years, soil loss from a bare ground surface was 1266 ton/ha compared with only 9 ton/ha from a similar soil protected by a mosquito gauze suspended 15 cm above the soil surface. The soil loss from the bare unprotected plot was 141 times more than the protected plot. The suspended mosquito gauze was an equivalent "energy breaker" that protected the soil against raindrop impact and soil detachment.

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Similar functions are performed by crop residue mulches. Data in Table 1 indicates the influence of mulch rate on runoff and erosion on an Alfisol near Ibadan, Nigeria. The mean soil loss on slopes of 1 to 15 percent was 77, 2.4, 0.4 and 0.1 kg/ha/mm of rain for mulch rates of 0, 2, 4 and 6 ton of straw/ha. Similarly, mean runoff losses were 286, 40, 14 and 8 mm for corresponding mulch rates.

Table 1 INFLUENCE OF MULCH RATES ON RUNOFF AND SOIL EROSION ON SLOPES OF 1, 5, 10 AND 15 PERCENT

Mulch rate t/ha	Runoff (mm)				Soil erosion (t/ha)			
	1	5	10	15	1	5	10	15
0	283	346	219	294	8	100	130	80
2	6	61	46	47	0.6	4	5	6
4	4	10	21	20	0.03	0.7	0.5	0.6
6	0	7	12	12	0.01	0.2	0.1	0.5

The mulch factor, the ratio of soil loss with mulch to corresponding loss with no mulch (Wischmeier 1973), also decreases exponentially with increasing mulch rates, (Table 2). Mulch rates of 2 to 4 t/ha are adequate to protect soil against erosion on slopes of up to 15 percent. For heavy soils and those containing expanding type clay minerals, however, these results have to be evaluated before making specific recommendations.

Table 2 MULCHING EFFECTS ON SOIL AND WATER CONSERVATION (M = Mulch rate in t/ha)

(a) Runoff

Slope %	R	Equation
1	0.85	$Y = 0.19\ M^{-0.54}$
5	0.85	$Y = 1.25\ M^{-0.71}$
10	0.96	$Y = 1.09\ M^{-0.67}$
15	0.72	$Y = 0.98\ M^{-0.24}$

(b) Soil erosion

Slope %	R	Equation
1	0.78	$Y = 0.39\ M^{-9.73}$
5	0.80	$Y = 1.16\ M^{-0.36}$
10	0.86	$Y = 5.53\ M^{-0.27}$
15	0.75	$Y = 5.26\ M^{-0.55}$

3. FACTORS AFFECTING CHOICE OF A TILLAGE SYSTEM

The short and long term objectives of seed bed preparation can be achieved by one of three methods: mechanical, chemical, and biological. The mechanical method of seed bed preparation is based on physical manipulation of soil (by ploughing and harrowing) and its principle advantage is weed control. Whereas this method controls weeds, by turning them under the soil, it also exposes the soil to raindrop impact and thereby accelerates soil erosion. The chemical and biological methods of seed bed preparation are designed to eliminate weed competition without attendant soil disturbance. Chemical weed control is based on the use of growth regulators (such as 2-4 D, Gramoxone, Atrazine etc.), the biological methods are based on increasing the competition for light, water, and nutrients by an easily suppressible aggressive crop (such as Stylosanthes guianenses, Pueraria phaseoloides, or Centrosem pubescens) or by eliminating light through the use of surface covers (residue mulches Neither the chemical nor the biological means of seed bed preparation involve soil disturbance, and therefore are erosion preventive techniques.

In addition to the socio-economic considerations, the choice of a suitable method for seed bed preparation depends on soil and climatic conditions, and the nature of crop to be grown (Table 3). It is generally believed that if weeds can be controlled by any other means, the usefulness of mechanical tillage as a method of seed bed preparation is questionable at best, and unnecessary and harmful at its worst.

Table 3 FACTORS AFFECTING CHOICE OF THE METHOD FOR SEED BED PREPARATION

Soil	Climate	Crop	Socio-economic (way of life)
1. Erodibility	1. Rainfall amount and distribution		1. Growing duration
2. Relief	2. Erosivity		2. Rooting characteristics
3. Rooting depth	3. Ambient and soil temperature regime		3. Water requirement
4. Moisture retention capacity	4. Periodicity and length of rainless days in the growing season		4. Seed size
5. Texture and structure	5. Water balance		5. Canopy structure
6. Organic matter content	6. Length of the growing season		6. Soil conserving or degrading crops
7. Physical and chemical characteristics of the sub-soil			
8. Tolerable limits of soil erosion			
9. Mineralogy			

4. SOIL AND WATER CONSERVATION THROUGH MULCH-TILLAGE

If there is no mechanical soil disturbance and the soil is protected against rain drop impact by residue mulches, there should be no accelerated soil erosion on slopes that are within 10 to 15 percent. Data in Table 4 indicate the runoff and soil loss on various slopes using mechanical and chemical tillage methods for growing soybeans near Ibadan. The runoff using mechanical tillage was 5 to 13 times that of the chemical tillage system. There was no soil erosion with chemical tillage within slopes of 1 to 15 percent, compared to 60 to 70 tonnes of soil loss per hectare with the mechanical method of seed bed preparation.

Table 4 SOIL EROSION UNDER SOYBEANS (GLYCINE MAX.) AS INFLUENCED BY METHODS OF SEED BED PREPARATION (AINA, LAL AND TAYLOR 1976)

Slope %	Chemical Tillage		Mechanical Tillage	
	Runoff (% of rainfall)	Erosion (t/ha)	Runoff (% of rainfall)	Erosion (t/ha)
1	0.7	0	3.7	0.4
5	1.1	0	18.2	21.9
10	1.7	0	22.9	66.1
15	1.7	0	15.0	68.0

The advantages of chemical seed bed preparation with residue mulches in soil and water conservation are indisputable. In addition, this method also helps maintain soil structure, soil organic matter content and nutrient and water holding capacity of the soil (Table 5). The benefits of maintaining an optimum soil temperature regime and a better environment for root system development and proliferation have also been observed.

A combination of chemical and biological systems of seed bed preparation can therefore be used to control erosion, conserve moisture, optimize soil temperature, and improve soil structure and organic matter status. Mulches, by virtue of limiting light, also provide protection against weeds. The question is, whether this system can be used on a commercial scale for arable crop production in the humid tropics.

Table 5 INFLUENCE OF TILLAGE SYSTEMS IN SOIL CHEMICAL CHARACTERISTICS UNDER MAIZE-MAIZE CULTIVATION (LAL 1976)

Soil characteristics	Chemical tillage	Mechanical tillage
pH	5.3	5.0
Organic carbon (%)	1.40	0.91
Total Nitrogen (%)	0.12	0.07
Bray-1 Phosphorus (ppm)	66.3	48.2
CEC (meq/100 g)	7.1	4.0
Exchangeable Ca^{++} (meq/100 g)	5.7	3.0
Exchangeable Mg^{++} (meq/100 g)	0.66	0.30
Exchangeable K^{+} (meq/100 g)	0.44	0.29

5. NO-TILLAGE FARMING

No-tillage is a system of seed bed preparation without primary or secondary cultivation where mechanical soil disturbance or manipulation is limited to seedling and fertilizer placement. Weed control is achieved by other means than mechanical soil manipulation, namely by chemical or biological techniques. A continuous cover of crop residue mulch is an essential component of this system. This tillage system is based on the zonal tillage concept, whereby the seed bed is divided into a seedling environment zone and a soil management zone. The seedling environment zone serves to provide the ideal conditions for seed germination, emergence and establishment. The inter-row soil management zone serves to conserve soil moisture, prevent runoff and erosion, and optimize the soil temperature regime.

Successful crop yields have been obtained with this tillage system under different soil and ecological environments (Table 6). It is generally belived that crop yields comparable to that of mechanical tillage can be obtained by this system in a normal season, and perhaps superior yields in a season with periodic drought stresses.

Though the potential of this system of seed bed preparation is unlimited, there are some practical considerations that must be kept in mind for increasing the adaptability of this system under different soil and climatic conditions. The versatility of the no-tillage system can be vastly increased by modifications of the system to adapt it under specific soil and environmental conditions.

Table 6 NO-TILLAGE OR MINIMUM TILLAGE EFFECTS ON CROP YIELD IN THE TROPICS OF AFRICA

Crop	No-till yield (% of ploughed)	Year	Location	Country	Source
Maize	233	1961	Kumasi	Ghana	Kannegieter (1969)
Maize	77	1967-68	Kangwa	Tanzania	Macartney, Northwood
Maize	98	1975	Ilora	Nigeria	Dagg and Dawson (1971)
Cowpea	117	1974	Ilora	Nigeria	
Maize	105	1975	Ikenne	Nigeria	
Cowpea	131	1974	Ikenne	Nigeria	
Maize	72	1974	Monrovia	Liberia	
Maize	215	1973	Monrovia	Liberia	
Rice	152	1973	Monrovia	Liberia	
Maize	78	1974	Obubra	Nigeria	
Maize	129	1975	Ibadan	Nigeria	
Sorghum	99.5	1974	Gabrone	Botswana	Whiteman (1974)
Maize	97.0	1973	Kampala	Uganda	Olum and Nenderlong (1975)

NB: Wherever a reference is not given, these results were obtained by the author and his colleagues.

5.1 No-tillage or Zero-tillage

Planting is done directly in unploughed soil with chemically killed sod, weeds, cover crops, or in the previous crop residue. In this method, paraquat or any other contact/systemic herbicide is used to replace mechanical seed bed preparation. Residual herbicides (atrazine, lasso, etc.) are used for weed control. Crops can be planted either by hand planter or by commercially available no-till planters. Whenever this system is used to seed through chemically killed sod/cover crop, the system is also referred to as "Sod Seeding".

5.2 Mulch Tillage

A chisel plough is generally used in the previously shredded crop residue to break open the hard crust or hard pan underneath the soil. Care is taken not to invert the soil, and to leave a maximum of the crop residue on the soil surface. Chemical weed control is obtained as necessary.

5.3 Strip Tillage

Mechanical tillage is eliminated in most of the inter-row zone, and a narrow strip is opened to facilitate planting and fertilizer placement. Crop residue mulch is left undisturbed in the inter-row zone.

5.4 Disc Planting

One discing prior to planting and leaving most of the crop residue on the surface can also help open a crusted field and improve its infiltration, water holding capacity, and root penetration. This technique is also called 'Minimum Tillage.' A common characteristic of all these sytems is the maintenance of surface residue mulch.

It is worth noting, that 70-80% of the advantages of no-till farming are attributed to surface residue mulches. Lack of the adequate amount of crop residue mulch will create problems of weed control, accelerated soil erosion, and general degradation of soil productivity.

The no-tillage farming system of soil management will also not work on compacted and degraded lands. The fertility of degraded and eroded lands should first be restored through the ameliorative effects of cover crops. One or preferably two years of fallow with cover crops such as Stylosanthes can help restore soil structure, improve organic matter content, and prepare the land for no-till farming.

6. CONCLUSIONS

Wherever soil and water conservation and the maintenance of soil organic matter content and soil structure are constraints to arable farming, the no-tillage system of seed is associated with mulch farming, and may not operate successfully without an adequate amount of surface mulch. This system can also be used on compacted, eroded and degraded soils after one or two years of cover crop fallow with Stylosanthes or Pueraria.

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Paper 4

SOME COMMON FARMING SYSTEMS IN CAMEROON, THEIR INFLUENCE ON THE USE OF ORGANIC MATTER AND THE EFFECTS OF SOIL BURNING ON MAIZE YIELDS AND ON SOIL PROPERTIES

S.N. Lyonga [1]

1. INTRODUCTION

Food crop production in Cameroon is predominantly on small-scale farms using simple farming implements. This activity involves annual soil preparation and constant but varying ways of incorporating vegetative matter into the cropping cycle.

The types of cropping systems practised to a large extent influence and sometimes determine the extent of incorporation of organic matter into the soil. The accumulation of organic matter in the soil is influenced by a number of factors including topography. Thus, there is a build up of organic matter over the years in soils at high and cooler altitudes.

2. SOME COMMON CROPPING SYSTEMS IN CAMEROON

There are various underlying reasons for the different cropping practices. Some of these include:

- meeting the local nutritional requirements (for humans and feed for animals);
- maximizing yield per unit area of land;
- even spread of labour;
- realizing the benefits from a catch or nurse crop;
- maintenance of soil fertility.

It should be mentioned that the maintenance of soil fertility is hardly considered, if at all, by the majority of peasant farmers.

The main and sub-groups of the various cropping systems are illustrated graphically in Table 1 and explained in the following paragraphs.

2.1 Mixed Cropping

2.1.1 Perennial crops intercropped with annual food crops

This system of cultivation is fairly widespread in most areas where cash crops are grown. It is practised most widely where population pressure on land is heavy and there is great demand for food. Thus, in the highlands of the Western and North-west plateaux, one finds coffee (Coffea arabica or C. robusta) intercropped with plantains or bananas, or with maize and cocoyams (Xanthosoma sagittifolium), dwarf beans (Phaseolus spp.) and local vegetables. No climbing plants are used for this combination. Economically, this combination results in rationalization of labour as the labourers used in planting the food crops are used in weeding as well as harvesting the coffee. A variation of this coffee and food crop relationship exists in some high lava plateau regions. Here, food crops such as maize, beans and cocoyams are planted first and are later interplanted with coffee. As the coffee matures, new areas are cleared to start the cycle again.

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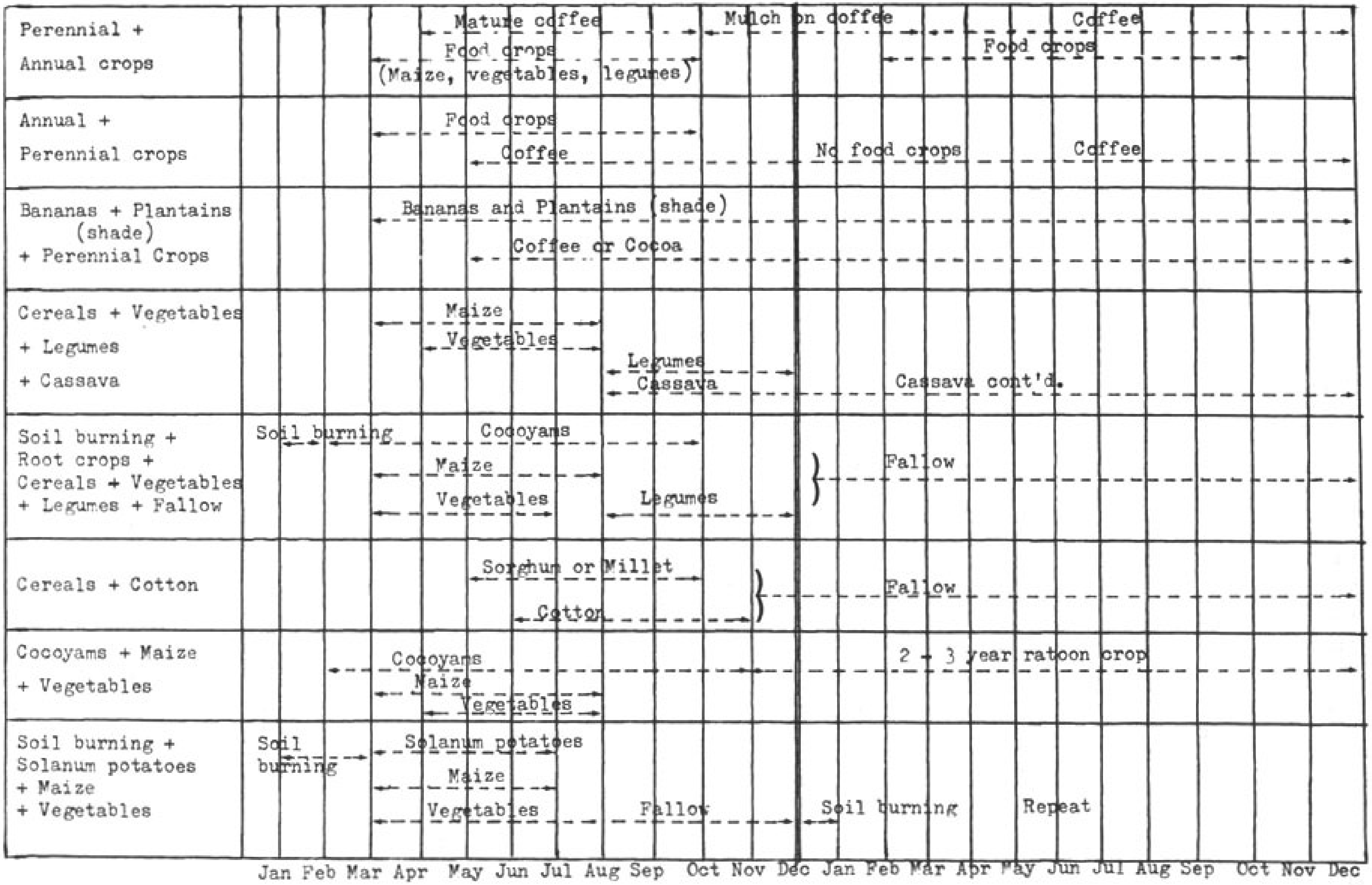
Table 1 CROPPING CALENDAR OF SOME COMMON CROPPING SYSTEMS IN CAMEROON



In this group of cultural systems organic matter is used in the form of mulching for the tree crops and during food crop cultivation; organic debris is buried and burnt when food crops precede coffee. Coffee factory waste (bran and chaff) are a useful organic manure source for coffee farms. It is estimated that up to a fifth of the weight of bean may go back to the farm as manure.

In the lowland cocoa area, one also finds, plantains and bananas among the cocoa. These provide the desired side and overhead shade necessary for cocoa especially when it is young. Cocoa is intercropped with cocoyams, maize, local vegetables, etc. when it is mature or old and declining in yield.

2.1.2 Intercropping between and rotations of different food crops followed by bush fallow

There are many variations of these and the number of crops differ greatly.

Usually, root crops like yams or cocoyams start the sequence, and are intercropped with cereals, e.g. maize. Leguminous crops follow towards the end of the rainy season. Cassava may be planted at the tail end of the dry season and will continue during the second year. This is followed by a grass fallow of varying duration depending on pressure on the land. A typical example of this system may be: yams + maize + local vegetables + beans + cassava followed by cassava in the second year + fallow 1 to 3 years.

A common food crop combination in the Western savannah highlands after the practice of soil burning is maize + cocoyam (Xanthosoma spp.) + Colocasia + trifoliate yam + vegetables, especially cabbage.

In the Western highlands, the following is also a popular crop association after burning: solanum potato + maize + local vegetables (spinach, melon, pumpkin).

In some parts of the North, as in Diamare, peasants attempt to combine sorghum (planted in June and harvested in October-November) with cotton which they harvest in November and December, followed by a short fallow.

Groundnuts are usually planted alone but some try to fit them with sorghum which is generally on a separate, adjoining piece of land.

On the black clay soils called "Karal" 'Muskwari' sorghum, which is drought tolerant, is usually planted towards the end of the wet season (September-October).

2.2 Sole Cropping - Plantation Monoculture

In this practice of monocropping (single crops) on a large scale, judicious clearing and planting in rows to allow organic material to rot between the crop rows can benefit both the crops and soil fertility. Unfortunately, many mechanical means of land preparation involve the removal not only of the vegetation but the top soil as well.

Subsequent beneficial practices are the planting of cover crops, e.g. Pueraria spp., Calapogonium spp., Centrosema spp., Mucuna spp., etc., on young rubber, and oil palm plantations. Apart from nutritional aspects of these covers, they control soil erosion and regulate soil moisture and temperature.

It is on this scale of agriculture that waste matter is recycled and utilized in the field as organic manures. Oil palm bunch refuse and other mill waste products return to the estates.

2.3 Mixed Farming

This involves the keeping of animals and growing of crops for their mutual benefit. Three of the common systems in Cameroon are given below.

2.3.1 Poultry, maize, soybeans, vegetables

Poultry dropping produces very rich farm yard manure for the crops. The maize and soya are used as feed.

2.3.2 Pigs, cassava, cocoyams or sweet potatoes or bananas

Similar relationship between animals and crops as in 2.3.1.

2.3.3 Cattle, maize, legume covers on pastures, vegetables

In addition to manures, some animals are trained for traction purposes.

This leads one to the farmer/grazier problem in the grasslands. The interesting aspect here is the lack of demarcation between farm and grazing land. As a result, there is the perpetual annual plague of grassland fires, most of which are deliberately started by graziers between December and March to enable the growth of fresh lush pasture during the next rains. These fires destroy farms and cause an enormous loss of vegetative material and surface organic matter. It is estimated that, depending on the length of fallow, 15-30 tons of vegetative matter to the hectare are lost annually through fires.

3. THE EFFECTS OF SOIL BURNING ON MAIZE AND ON SOIL PROPERTIES

The practice of burning vegetative material which has been buried in soil beds or mounds is common among the food growers of the Western and North-Western Highlands and has received criticism and litigation. Little work has been carried out to assess its real dangers and the advantages derived from "Ankara" as it is locally called.

IRAF has undertaken some studies on this during the past five years on ferrallitic soils at an altitude of about 1 400 metres to examine the availability of phosphorus and the effect on the physical and chemical characteristics of the soil.

Materials and Methods

In 1973, 12 plots (200 m^2) were burnt and no manure was added. Two plots were used as the control, without burning and without manure. The design was non-statistical.

In 1974, each plot burnt in 1973 was divided into two parts: one part was burnt again, the other half was not burnt and the crop residues were buried (without manure). The two control plots of 1973 were maintained.

In 1975, 76 and 77, the treatments of 1974 were maintained except that phosphatic fertilizers (50 units of P_2O_5/ha) were applied in 1975 on the half plots in which crop residues were incorporated and 40 units of N + 100 units of P_2O_5 in 1976 and 1977.

The usual practice of underground burning the vegetative matter was carried out. Maize (Variety 290) was planted as the test crop. The results are presented in Table 2.

Table 2

YIELD OF MAIZE
quintals/ha

Treatments	1973	1974	1975	1976	1977	Mean
Plot burnt every year	60.0	59.3	67.7	77.8	60.7	65.1
1/ Plots burnt in 1973 and without manure	60.0	26.9	-	-	Late Sowing Dry Year	
1/ Plots burnt in 1973 without manure in 1974 with 50 P in 75	60.0	26.9	41.3	-		
1/ Plots burnt in 1973 No manure in 1974 50 P in 1975 40 N + 100 P in 1976	60.0	26.9	41.3	63.3	45.0	
Control: No burning, no manures	18.0	13.0	8.5	15.4	28.5	16.7

1/ Residues buried after harvest.

The results indicate high yields (mean 65.1 q/ha) for plots burnt yearly as against 16.7 q/ha for the control. There was little beneficial residual effect of burning. The introduction of 50 units/ha of P_2O_5 in the third year permitted the re-establishment of the equilibrium of P_2O_5 availability compatible with higher yields. N + P_2O_5 in the 4th year increased yields further by 22 quintals.

The effects of soil burning on the physical and chemical characteristics of the soil are presented in Table 3.

The results indicate that burning has caused:

- a reduction in clay content;
- a slight decrease in the C/N ratio;
- an increase in the level of total exchangeable bases;
- an increase in soil pH (both water + KCl);
- an increase in the amount of available P_2O_5.

Table 3 CHANGES IN CHEMICAL CHARACTERISTICS OF SOIL AFTER BURNING
(Bansoa: Ferrallitic complex soil; altitude: 1400 metres)

		No soil burning Normal sampling 1/		Soil burning 1st year		Soil burning 2nd year		Soil burning 3rd year	
		0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm
GRANULOMETRY	Clay %	18.2	13.8	17.8	11.2	7.6	5.8	-	-
	Silt %	19.5	24.9	17.8	26.9	14.9	14.7		
	Very fine sand %	8.8	10.3	8.9	8.5	10.5	8.3	2/	2/
	Fine sand %	21.5	20.1	21.6	20.0	25.9	26.6		
	Coarse sand %	32.0	30.9	33.9	33.4	41.1	44.6		
ORGANIC MATTER	Carbon %	4.51	4.62	4.17	4.05	4.11	2.08	5.40	5.22
	N Total %	3.25	3.45	3.15	3.40	3.47	2.36	4.63	3.98
	C/N	14	13	13	12	12	9	12	13
EXCHANGEABLE	Ca meq/100 g	8.40	8.90	7.65	7.75	13.35	16.75	9.40	10.40
	Mg "	2.40	2.45	2.85	2.85	4.85	6.40	4.40	5.50
	K "	0.55	0.44	0.85	0.82	2.84	5.77	2.80	5.40
BASES	Na	0.06	0.05	0.06	0.06	0.05	0.04	0.09	0.09
	Total	11.41	11.85	11.41	11.48	20.39	28.96	16.69	21.39
	CEC	26.30	26.30	25.40	24.70	23.35	21.90	23.00	23.00
	Saturation V $\frac{S \times 100}{CEC}$	43	45	44	46	80	100	72	93
pH	pH (water)	5.76	5.80	6.01	6.01	6.90	7.80	6.60	7.00
	pH (Kol)	4.91	4.95	5.22	5.19	6.16	7.10	5.80	6.30
P_2O_5	P Total Nitric	860	855	765	700	950	1080	790	750
	P Olsen	96	101	120	120	287	460	380	590
	P Saunder	190	177	177	250	540	590	630	675
	P Al	61	64	79	76	262	388	-	-
	P Fe	112	100	130	112	210	148	-	-
	P Ca	46	52	47	47	128	78	-	-
	P Orga	299	287	205	215	122	-	-	-

1/ Soil analysed one month after sampling.

2/ Not analysed.

4. DISCUSSION AND CONCLUSION

This short discussion on the various patterns of cultivation in Cameroon indicates some aspects of the present role of organic materials in Cameroonian agriculture and shows that they can play a greater part in the future in view of the ever-increasing cost of artificial fertilizers; and in reducing the period of bush fallow due to increased pressure on the land.

There is considerable evidence in the literature of the response of many tropical crops to organic manures. Wood (1933) in Trinidad and Stephens (1960) in Ghana, showed the positive response to organic manures by yams (Dioscorea spp.) although the results presented by Rouanet (1967) showed little benefit in the volcanic soils of Guadaloupe to Dioscorea trifida. Vine (1953) in Nigeria found the effects of green manures and raw organic manures transient but agreed with Wood (1933) that manures should be rotted before incorporation into the soil.

A positive correlation coefficient of 0.98 between organic carbon and cation exchange capacity has been reported by Djokoto and Stephens (1961) in Ghana and of 0.81 between organic carbon and yield.

In addition to the chemical advantages of organic matter, its positive influence on the physical properties of the soil because of its effect on soil temperature, moisture, etc. should be considered to be of great importance.

Regarding the economics of artificial fertilizers (urea and KC1) used on yams in Cameroon, it has been shown that a price of 30 francs per kilogram of either fertilizer (utilized in a mixed dose of 200 kg/ha and 220 kg/ha respectively) was close to the limit of their profitable use. On the other hand, 8-10 tons of compost per hectare, which produced an equivalent increase in yield, gave a higher margin of profitability.

The study on soil burning has indicated the following advantages of this practice:

- it liberates P_2O_5 in assimilable form;
- it makes the mineral nutrients readily available to the crops, for example, potash in carbonate form;
- it disinfects the soil by killing some harmful micro-organisms like Pseudomonas bacterium which causes wilt;
- it raises pH from very acidic to desirable levels.

The disadvantages of burning include:

- the destruction of clay;
- the destruction of organic matter;
- the raising of pH to levels that may impair availability of some nutrients;
- the destruction of useful micro-organisms.

The change in soil structure and texture enhances soil erosion.

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Paper 5

EFFECT OF DIFFERENT CROPPING SYSTEMS ON CROP, YIELD AND SOIL FERTILITY MANAGEMENT IN THE HUMID TROPICS

Akinola A. Agboola [1]

1. INTRODUCTION

A common feature of traditional farming systems of the humid tropics is the growing by each farmer of several species of crop plants and numerous varieties of each species (Okigbo and Greenland 1975). The number of species of crops grown by some people in different parts of Africa are presented in Table 1 . Miracle (1967) as quoted by Okigbo and Greenland (1975) observed that in Zaire, the Medje grew as many as 80 varieties of the 30 species of food crops they cultivated in 1911. Of these, 27 varieties consisted of bananas and plantains, and 22 varieties were yams and related crops. Similarly in southern Mamva, northern Mongo, Lukumba village and Manilode village of Zaire, the numerous species of crops grown consisted of over 60, 70, 33 and 34 varieties respectively. Of the 70 varieties grown in the northern Mongo area of Zaire, 53 varieties consisted of bananas and plantains. The various varieties of each crop species exhibit different characteristics, mature at different times and may be adapted to different ecological situations and cultural practices.

A cropping system is a crop production technique involving a space and time arrangement of one or more crops to maximize productivity per unit area of land. The choice of a cropping system depends on the physical environment, socio-economic factors and specific objectives of the farmer. This means that there must be a large number of cropping systems in the humid tropics.

2. MAJOR CROPPING SYSTEMS IN THE HUMID TROPICS

The most common traditional cropping system involves spatial arrangement of crops on the field. The crops are apparently established haphazardly in mixed culture. This pattern according to Okigbo and Greenland (1976) usually involves location and spacing of plants in such a way as to:

i. take advantage of local topographic features, toposequences, microrelief and other related peculiarities;

ii. disperse individual plant species at such wide spacing as to allow other crops to be grown in between without unnecessary overlapping of their canopies;

iii. ensure that crop cover is adequate to effectively control soil erosion and weeds; and

iv. ensure that heliophytes are grown more in open spaces while shade tolerant species such as cocoyam are located under trees and along hedgerows. Where annual staples are uniformly planted among tree crops, heavy pruning of the tree crops is usually carried out to ensure that light reaches ground level. Whether crops are grown on mounds, beds, ridges or on the flat, their spatial arrangements and frequencies in mixtures are usually related to their importanc in the diet and sometimes to their use.

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Table 1

CROP COMBINATIONS* IN DIFFERENT LOCATIONS OBSERVED IN 100m^2 SAMPLE PLOTS IN RELATION TO SEED BED PREPARATION

Crop	Ogidi (Mounds)	Abagana (Mounds)	Umuleri (Mounds)	Awka (Mounds)	Ezillo (Mounds)	Abakaliki (Mounds)	Ikom (Mounds)	Oron Flat	Ibam Ekpe Flat	Onne 1 Flat	Onne 1 Flat	Percentage Frequency
Dioscorea rotundata	X	X	X		X	X	X	X	X	X		82
D. rotundata (Abi)		X		X								18
D. dumetorum						X		X	X	X		36
D. bulbifera					X	X						18
D. alata			X		X	X		X				36
D. cayenensis sp								X				9
Cassava (*Manihot* sp)		X		X	X	X		X	X	X	X	64
Cocoyam (*Xanthosoma*)			X	X			X	X	X			45
Cocoyam (*Colocasia*)			X		X			X	X			36
Sweet potato			X									9
Musa sp				X			X		X			27
Maize (*Zea* sp)	X	X	X	X	X	X	X	X	X	X	X	100
Cowpea (*Vigna* sp)			X		X							18
Groundnuts (*Arachis* sp)					X	X	X					27
Voandzeia sp					X							9
Sphenostylis sp								X				9
Solanum sp	X		X									9
Capsicum sp												18
Okra (*Hibiscus* sp)	X	X	X		X	X	X	X	X			73
Pumpkin (*Cucurbita* sp)	X	X						X				27
Melon (*Colocynthis* sp)	X	X	X	X		X	X					55
Telfairia sp					X				X			18
Lagenaria sp					X	X						18
Amaranthus sp	X		X	X								27
Corchorus sp	X		X	X			X		X			45
Bitter leaf (*Verooria* sp)									X			9
Talinum triangulare							X	X				18
Castor bean (*Ricinus* sp)	X		X	X	X							36
Sugar Cane (*Saccharum sp*)								X				9
No. of species per sample	9	7	13	9	13	10	9	13	12	4	2	

*Okigbo and Greenland (1976).

2.1 Multiple Cropping

The most widespread 'multiple' cropping system practised in the humid tropics consists of mixed intercropping, relay intercropping and row intercropping.

2.1.1 Mixed intercropping

Mixed intercropping encompasses a wide array of apparently random arrangements of several crops in a field. Mixed intercropping is common when cereals, grain legumes and root crops are grown together and when little or no tillage is practised. For example, farmers in southern Nigeria plant simultaneously, maize, cassava, vegetables and cocoyam. Mixed intercropping is also practised in mounds or ridges of soil constructed with hoes in Abakaliki, Nigeria. Several crops are planted on different parts of the mounds. Abakaliki farmers may plant yams on the mound, rice in the furrow, maize, okra, melon and cassava at the lower parts of the mound. Mounding is beneficial because it increases the volume of soil available to root crops.

2.1.2 Relay intercropping

This is a practice where a second crop is planted after the first crop has entered the reproductive growth phase but prior to harvest. A common example is a maize-bean system in most of Central America and much of tropical South America (Sanchez 1976). Maize is planted in rows usually at the beginning of the rainy season. When the ears are well formed farmers break the stalks just below the ear, and plant climbing bean varieties. Relay intercropping is also very common in rice-based systems in Taiwan. Up to five crops per year might be harvested by two relay successions, rice/melon followed by replanting with rice and relaying with cabbage and maize. At present, maize cassava relay is being developed at the University of Ibadan, particularly with reference to soil nutrients. Maize is planted with the early rains in March/April, and is followed by cassava early in June or at about tasselling time. The maize is harvested in August and the cassava early in July of the following year; this is followed by the planting of late maize in August and the cassava is again relay-cropped in October, thus the cropping system covers 1½ years.

2.1.3 Row intercropping

This occurs when one or more crops are planted at about the same time in rows which are close to each other. Row intercropping is common in tilled areas. Competition between species for light, water and nutrients is on row basis except when two crops are planted in the same row. Row intercropping is most advantageous when a tall crop is mixed with a short one, and when the crops have different growth duration because the stages of maximum demand for light, water and nutrients occur at different times even though both crops are planted at about the same time. Row intercropping of annual crops under perennials is very common. Tall growing crops such as maize, cassava or bananas are planted in young coffee, cocoa or rubber plantations to provide shade and produce income (Sanchez 1976).

2.2 Sole Cropping

Sole cropping is the growing of a crop variety or species in pure stands. This is the system least practised by the local farmers. It is a common practice on the government farms, research stations and University farms.

3. CROP YIELD

About two decades ago, researchers frowned at working on intercropping, multiple cropping, etc., because it was considered primitive. In 1964, the University of Ibadan had no data on intercropping, etc., but it was assumed that the overall yield on a hectare basis for intercropping or multiple cropping should be higher than sole cropping. In 1965 a series of experiments on the intercropping of legumes with maize and later on multiple cropping of various crops were conducted to study the effect of these cropping systems on yield and soil fertility. These series of experiments started in 1966 and some are still continuing in collaboration with IITA.

It had been observed that very few experiments had been carried out to compare pure stands of crops with interplanting. It had already been established that, provided planting was done at the best time, the modest reduction in the yield of interplanted crop was offset by the production of the other crop and that this system gave a higher cash return per hectare than sole cropping. Table 2 shows the result of an experiment conducted for four years (1972-76) at the University of Ibadan to compare the performance of maize interplanted with different legumes using different cropping patterns. This was a split plot experiment in a randomized block design. Both maize and legume were planted on the same day. The result indicated that the planting pattern had no effect on maize yield. The legume intercrop did not affect the maize yield, although the legume yield was reduced drastically.

Table 2 EFFECT OF DIFFERENT PLANTING PATTERN ON MAIZE YIELD 1/ (kg/ha)

Intercrop	Cropping pattern	-	F
Nil		1 890^{b}	2 490^{a}
		1 950^{b}	2 680^{a}
		1 850^{b}	2 580^{a}
Cowpea	in between row	1 750^{c}	2 150^{ab}
	same row	1 750^{c}	2 080^{ab}
	alternate row	1 845^{b}	1 880^{ab}
Calopo	in between row	2 045^{a}	2 150^{ab}
	same row	2 030^{a}	1 960^{ab}
	alternate row	2 115^{a}	2 045^{ab}
Greengram	in between row	1 720^{c}	2 260^{ab}
	same row	1 880^{b}	2 180^{ab}
	alternate row	2 110^{a}	2 050^{abi}

1/ Average yield of maize for 4 growing seasons

In another experiment involving maize and cassava, the time of planting the cassava intercrop played an important role on the yield of both intercrops. The experiment was conducted at Badeku village, which is about 20 km from the University of Ibadan. This was a split plot experiment in a randomized complete block design with four replicates. The plant populations for both crops were the same as for sole cropping. A fertilizer mixture 80-30-60 was banded on one side of the maize row at planting. The result (Table 3) indicated that the cropping pattern did not affect the yield. However, the time of seeding the intercrop affected the maize. This is an area worth investigating. At present, the farmers who intercrop cassava with maize are advised to plant at or near the tasselling stage. This will give a good coverage of the soil at the time the maize is being harvested, thus guarding against erosion.

<u>Table 3</u> EFFECT OF TIME OF INTERCROP ON YIELD AND CASSAVA AND MAIZE INTERCROP

		Cassava	Maize
		Yield[1] in kg/ha	
	Planting pattern		
Sole cassava	-	8 600^{a}[2]	-
Sole maize	-	-	2 500^{a}
Cassava at 0 weeks	same row	7 600^{ab}	1 400^{b}
	in between rows	7 400^{ab}	1 600^{b}
Cassava 2 weeks after	same row	7 000^{b}	2 000^{ab}
	in between rows	7 200^{b}	2 000^{ab}
Cassava 5 weeks after	same row	7 600^{ab}	2 200^{ab}
	in between rows	8 000^{a}	2 100^{ab}
Cassava 8 weeks after	same row	8 250^{a}	2 600^{a}
	in between rows	7 960^{a}	2 750^{a}

[1] Average yield for 3 crops of each.

[2] Means having the same letter are not significantly different from each other at 5% level of significance.

The latest experiment on traditional mixed cropping and intercropping systems in the tropics involved treatments shown in Table 1. The result has shown that leaf area index can be used in the selection of crops that can be combined. Where maximum leaf area index of two crops occurs at the same time, the yield of the shaded one is adversely affected (Fig. 1).

The effect of different crop combinations on the yield of those crops is given in Table 4.

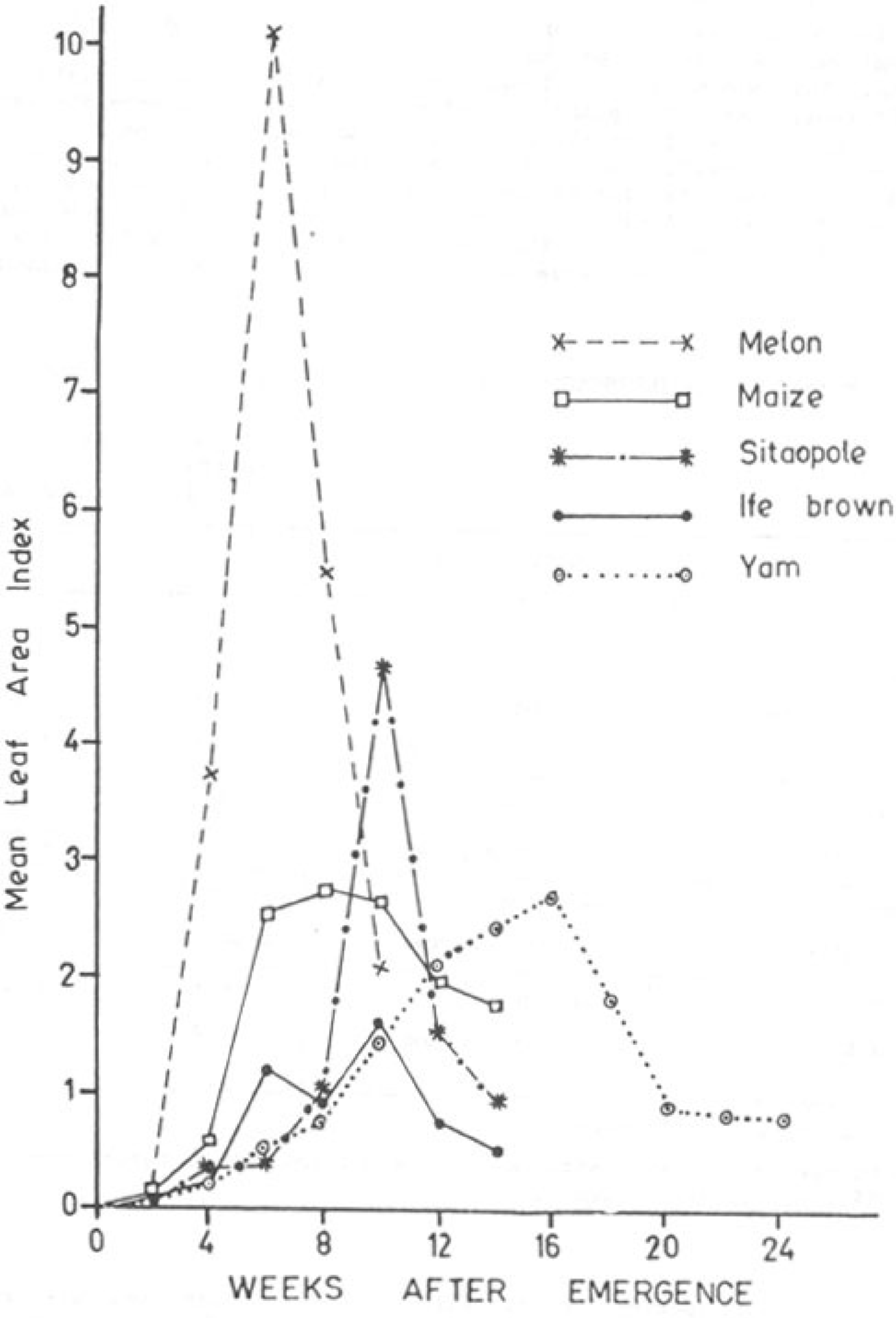


Fig. 1 Leaf area index of various crops intercropped at IITA in 1976

Table 4

EFFECT OF DIFFERENT CROP COMBINATIONS ON YIELD OF COMPONENT CROPS

	1975 Dry weight yield of component crops kg/ha/day						1976 Dry weight yield of component crops kg/ha/day					
	Maize	Melon	Cowpea		Yam	Mixture means	Maize	Melon	Cowpea		Yam	Mixture means
			1/TVU 1190	Climbing					1/Ife Brown	Climbing		
Maize	29.42	1.72	9.94	1.78	20.87	8.58	54.72	4.25	1.30	1.12	24.30	7.74
Melon	23.50	16.61	22.43	4.21	-	16.71	46.45	15.25	6.77	3.16	-	18.78
Erect cowpea	15.84	0.71	19.93	-	19.42	11.99	47.22	5.38	5.46	-	31.26	27.95
Climbing cowpea	20.28	5.70	-	6.75	21.16	15.71	33.95	4.89	-	4.91	19.86	19.57
Yam	24.66	-	16.52	3.92	41.07	14.97	34.92	-	3.57	2.16	37.06	13.55
Yam/Maize/ Melon/Cowpea	17.25	0.97	5.00	1.50	22.79	9.50	37.54	1.20	1.61	0.73	15.39	11.29
Crop means	21.83	5.14	14.76	3.59	25.06	-	40.80	6.19	3.74	2.42	25.57	-
Sole crop	29.42	6.61	19.93	6.75	41.07	22.76	54.72	15.25	5.56	4.91	37.06	23.48
In combination with one crop	21.07	2.71	16.30	3.24	20.40	12.74	40.64	4.84	3.88	2.15	25.14	15.33
In combination with three crops	17.25	0.97	5.00	1.50	22.79	9.50	37.54	1.20	1.61	0.73	15.39	11.29

1/ TVU 1190 and Ife brown are improved varieties of cowpea

4. SOIL FERTILITY MANAGEMENT

Jones (1975) wrote that under true subsistence farming there is considerable recycling of nutrients. Losses are restricted to volatilization of nitrogen and sulphur, largely through burning and to a certain extent a probably limited amount of leaching of nitrate and cations. Gains include small atmospheric contributions of nitrogen and sulphur, microbiological fixation of nitrogen and the drawing up of nutrients, particularly phosphate and cations from depth by fallow vegetation.

4.1 Nutrient uptake

Most workers agree that intercropped mixtures extract more nutrients from the soil than single stand. An experiment conducted at the University of Ibadan has confirmed this. Table 5 presents data on average nutrient uptake per annum in the crop mixture, more nitrogen and potassium being extracted than other nutrients.

4.2 Fallowing

The predominant practice of maintaining soil fertility is bush fallowing involving consecutive cropping periods of one to five years alternating with fallow periods of from two to 15 years depending on the population pressure on the land. In the densely populated areas of the Eastern States of Nigeria, fallows of Acioa barteri E. and Anthonotha macrophylla are planted while in the Western States of Nigeria Gliricidia sepium is usually grown. Permanent cultivation with no fallow or very short fallow periods is practised in the compound farms on floodland and terraces.

Table 5 EFFECT OF MAIZE PLUS CASSAVA INTERCROP ON NUTRIENT UPTAKE

	Sole Crop	Maize + Cassava intercrop p/a	Maize, Cassava Cowpea intercrop	Maize, Cassava Melon and Okra intercrop
Maize: Yield in kg/ha	2 400	1 600	1 400	1 350
N uptake kg/ha	61	112	130	120
P uptake "	9	14	19	17
K uptake "	45	100	130	120
Ca uptake "	8	18	20	22
Mg uptake "	11	17	16	14
		+ Maize and Cassava were planted on the same day. Cassava lasted 1 year.	Maize, Cowpea and Cassava planted on the same day. Cassava lasted 1 year.	

Soil analysis
pH 6.2
OM 1.6
Av. P. 10 ppm
K 70 ppm

N.B. 1. Cowpea had no yield
2. Melon yield was low
3. Okra was planted as late crop
Cowpea as early crop

As a result of experiments conducted by Faulkner in the 1930s and reviewed by Vines (1954), the Federal Department of Agricultural Research in Nigeria advocated that in a continuous rotational sole cropping, a farming system should include Mucuna as a green manure. This system was not accepted because peasant farmers considered it unprofitable to grow a crop for a season only to dig it into the soil without any immediate returns either in terms of cash or food. Moreover, their type of tools cannot cope with such operations. They are only familiar with the multicropping system. Bromfield (1967) suggested sole cropping of cowpea in the rotation hoping that it would meet the objection of local farmers.

Results of experiments reported by Agboola and Fayemi (1972), as shown in Fig. 2, indicated that intercropped legumes, namely greengram (*Phaseolus aureus*) cowpea (*Vigna sinensis*) and *Calopogonium mucunoides*, grown without fertilizers, gave a maize yield equivalent to 55 kg/ha of N supplied as mineral fertilizer. Calopogonium, cowpea and greengram fixed nitrogen when planted alone and when intercropped with maize. Legumes grown over the same period provided very little benefit to non-legume companion crops, but greengram was an exception, because when intercropped with an early crop of maize the latter showed an increase in yield. There was no significant yield difference between an early crop of maize in plots intercropped with greengram and plots where 55 kg/N/ha was applied. This was attributed to NO_3-N supplied by the nodules which had started to disintegrate after six weeks and thus provided for an early crop of maize. However, sole cropped or intercropped greengram with an early crop of maize contributed little to the yield of a late crop of maize. Greengram, produced a low crop residue because it flowered six weeks after planting and very little residue was left at the time of turning it under for the late crop of maize.

The result of this experiment indicated that fertility can be improved by the use of intercropped legume to grow some crops. This has a limit. Under intensive cultivation the intercropped legume should be supplemented with inorganic fertilizers.

4.3 Nutrient Requirement of Crops

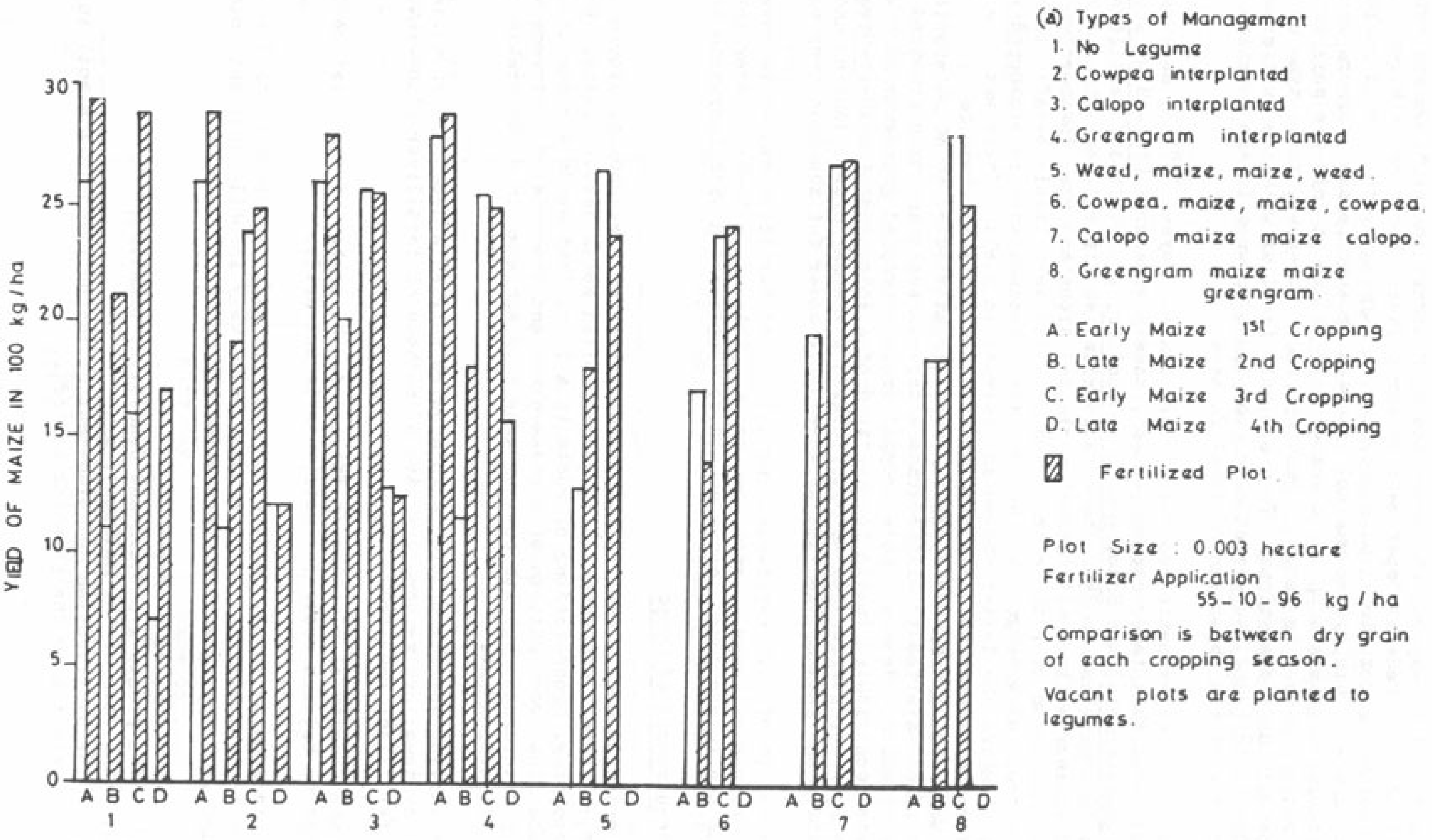
In order to meet plant needs and effectively utilize subsoil stored water, roots must proliferate continuously into unexploited zones between rains. Under multiple cropping, cross-feeding of roots is a force that needs serious attention. However, the final root pattern of a given plant and its rate of achievement is genetically determined, but its optimum growth is achieved in a favourable physical and chemical environment.

The varying ability of plants to acquire nutrients depending on variations in their root systems involves consideration of methods of fertilizer placement and the amount of fertilizer required.

As the density of planting is increased, the number of root systems increases and competition between roots for nutrients is intensified.

Plants such as maize, cassava and yam have different rooting habits and therefore differ in their ability to obtain the relatively immobile nutrients needed for optimum yield. Cropping yields are related to:

i. the kind of plant;
ii. the planting pattern and density of planting;
iii. the form of the nutrient; and
iv. the distribution and placement of the nutrient in the soil in relation to the planting pattern.



Plot Size : 0.003 hectare

Fertilizer Application 55 - 10 - 96 kg / ha

Comparison is between dry grain of each cropping season.

Vacant plots are planted to legumes.

Fig. 2 Effect of different soil management system on yield of maize.

4.3.1 Soil fertility evaluation

Soil test correlation and calibration is easy with sole cropping, but under intercropping or multiple cropping, no suitable method has yet been devised. It is known that soil testing is the most important single guide to the profitable application of fertilizer and lime. When soil test results are combined with information about the nutrients that are available to the various crops from the soil profile, the farmer has a reliable basis for planning his fertility programme.

Using the nutrient calibration for sole cropping has not proved suitable for the assessment of nutrient demand in mixed cropping. Under Western Nigerian conditions, a crop of maize would not respond to P fertilizer once the soil test is more than 10 ppm.

Table 5 shows that a crop of maize extracted 9 kg P/ha, whereas when cassava was intercropped the P uptake went up to 14 kg/ha. At the same time, optimum yield of each crop was not achieved. It is therefore suggested that soil test calibration and correlation under multiple cropping should be given urgent attention.

4.3.2 Methods of fertilizer application

Due to the nature of tropical soils, researchers often advise farmers to side dress or band fertilizer. This is very easy under sole cropping and row interplanting, but in multiple cropping the only alternative is by broadcast. Broadcasting requires more fertilizer than banding. On high fertility soils, maintenance fertilizer can be applied. Knowledge of nutrient uptake of component crops can therefore be a useful tool. However, on low fertility soils it would be advisable to build up the nutrient status of the land before embarking on maintenance fertilizer.

4.3.3 Type of fertilizer

The fertilizer materials currently in use for food crops in Nigeria are the 15-15-15 and 25-10-0 compound fertilizers. Although fertilizer may be sold separately as ammonium sulphate, single superphosphate and muriate of potash, the danger lies in the fact that the fertilizers at present recommended supply only one or two nutrients and most exclude micronutrients. It has been found that where tropical soils are cropped continuously for long periods without fertilizer or using only N and P sources, levels of exchangeable cations, Ca, Mg and K drop dramatically and the soil becomes increasingly acid. Fertilizers, such as ammonium sulphate, should not be used on acid soils.

To improve such situations, a great deal needs to be known on the nutrient balance of tropical soils under different cropping patterns. A multinutrient fertilizer is at present being tested in the Northern States of Nigeria; it contains (on a percentage basis) 12 N, 5.3 P, 10 K, 1.2 Mg, 5.0 Ca, 8.0 S, 0.1 B, 0.1 Mn, 0.02 Zn and 0.0005 Co. This may not be the best formula but it is a step in the right direction.

5. ROLE OF ORGANIC MATTER AND ORGANIC MATERIALS IN SOIL FERTILITY MANAGEMENT

Organic matter contributes to plant growth through its effect on the physical and biological properties of the soil.

One of the causes of yield reduction under continuous cultivation in the tropics is a rapid decline of soil organic matter under continuous cultivation. The greatest benefits of fallow are the accumulation of crop nutrients in the topsoil by recycling and fallow ash, the increase of soil organic matter and the suppression of the weeds, pests and diseases. Soil structure is also improved. Under continuous use, the soil structure breaks down. In the absence of fallow, another way of maintaining soil fertility could be through the disposal of organic wastes produced each year from domestic and municipal sewage, food processing industries, etc. In large cities like Ibadan and Lagos the wastes are causing pollution.

All organic wastes have properties in common in that they are made up of carbon, hydrogen, oxygen, and sulphur. Residues from agriculturally oriented industries are made up of many of the constituents found in crop residues, such as lignin and cellulose, although not necessarily in the same proportion. The wastes from paper and sugar mills are high in carbohydrates while those of meat packing and dairy processing industries contain relatively large amounts of fatty acids and protein. Wood residues would be expected to be relatively rich in lignin.

The faeces of farm animals consist mostly of undigested food that has escaped bacterial action during passage through the body. This undigested food is mostly cellulose or lignin fibres, although some modification of the lignin to humic substances has probably occurred. The faeces also contain the cells of micro-organisms.

Animal wastes are more concentrated than the original feed in lignins and minerals. Lipids are present along with humic-like substances. The nitrogen content of manure is higher than that of carbonaceous plant residues such as maize stalks, which means that mineral nitrogen reserves will not be depleted during decomposition in the soil. Manures also contain a variety of trace organics, such as antibiotics and hormones.

The suitability of domestic sewage as a soil amendment has been greatly increased by previous biological treatment which not only stabilizes the material but eliminates pathogens and obnoxious odours. The main purpose of treating municipal sewage has been to reduce the amounts of suspended solids, bacteria, and oxygen-demanding material to an acceptable level for discharge into streams or lakes. With more stringent water quality standards, greater emphasis in the future will be given to disposal on land.

It should be noted that little if any environmental damage is expected when sewage sludge is applied to agricultural land at rates which supply adequate but not excessive amounts of plant nutrients. The main environmental concern is from repeated applications over a prolonged period, particularly at high rates.

5.1 Role of Mulching and Organic Material

Figs. 3 and 4 show the result of an experiment on continuous use of organic manure for continuous cultivation in the Sahel Savannah Zone of Northern Nigeria. The experiment has lasted for 24 years. The treatments employed were an annual application of 0, 2.5 and 5 tonnes (D_0, D_1, D_2) of organic manure, 0, 10 and 32 kg N (N_0, N_1, N_2); 0, 4.5 and 9 kg P (P_0, P_1, P_2) and 0, 14 and 28 kg K (K_0, K_1, K_2) per hectare.

The results have effectively demonstrated the advantage of organic manure plus fertilizer over the use of inorganic fertilizer alone.

The cropping of virgin land regardless of tillage practices has been found to lead to a decline in the organic matter content but there is a rapid recovery with the introduction of mulch (Fig. 5).

The organic matter level was best maintained with zero tillage treatments; for example, two years after mulching, zero tillage treatment improved from 1.65 to 3.50%, which is an increase of 20% over the organic matter content of the soil before the experiment as compared with the lower value of 1.4 to 2.7% recovery rate on tilled plots. Tillage practices have been found to increase the oxidation process of soil organic matter, thus reducing the recovery rate of the organic matter.

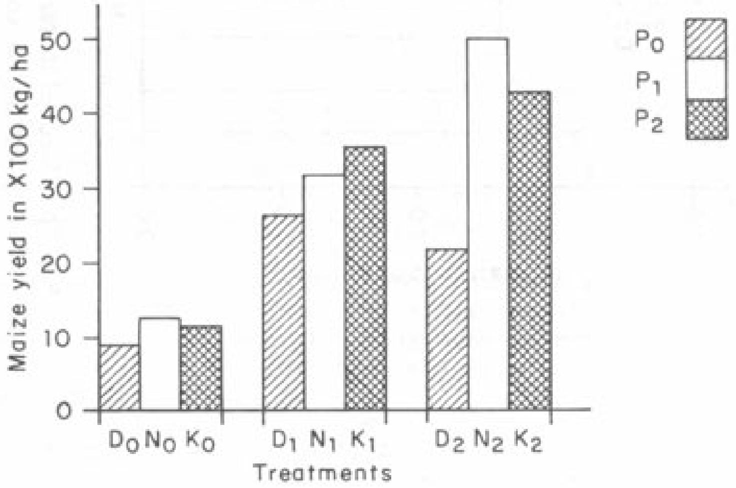


Fig. 3 Effect of farm yard manure (D) and fertilizer on yield under continuous land use

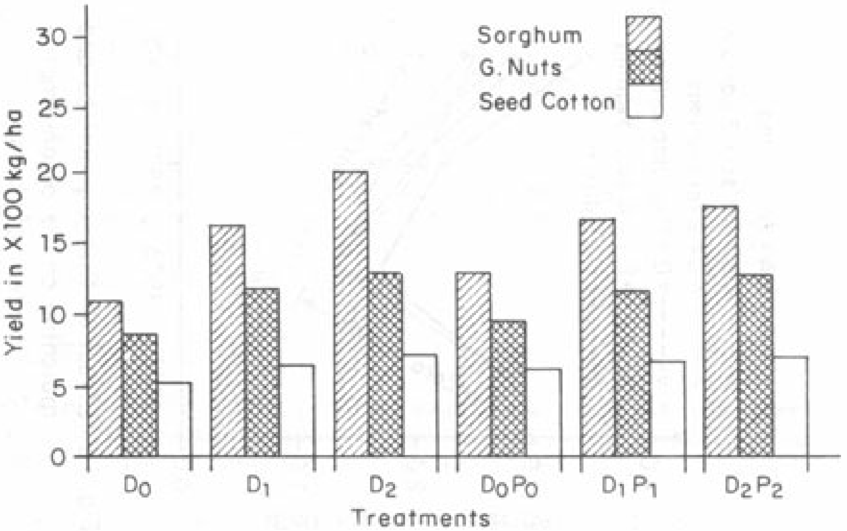


Fig. 4 Effect of continuous use of farm yard manure (D) and fertilizer on crop yield under continuous land use

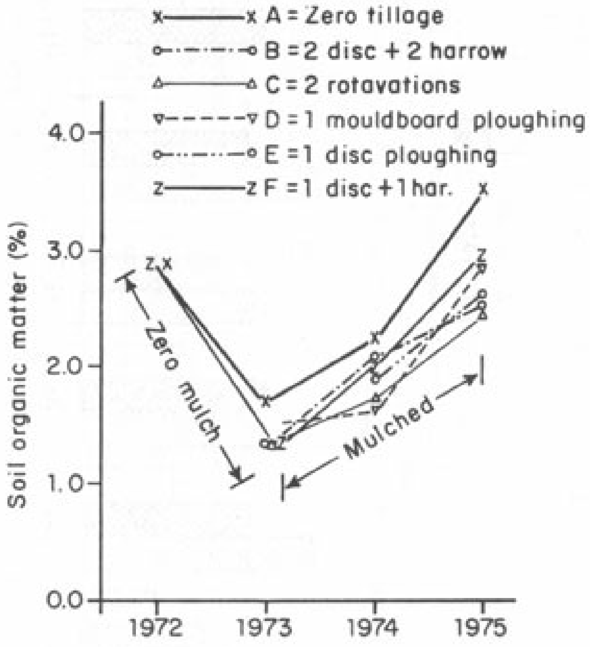


Fig. 5a Effect of tillage practices and mulching on the organic matter content of the soil

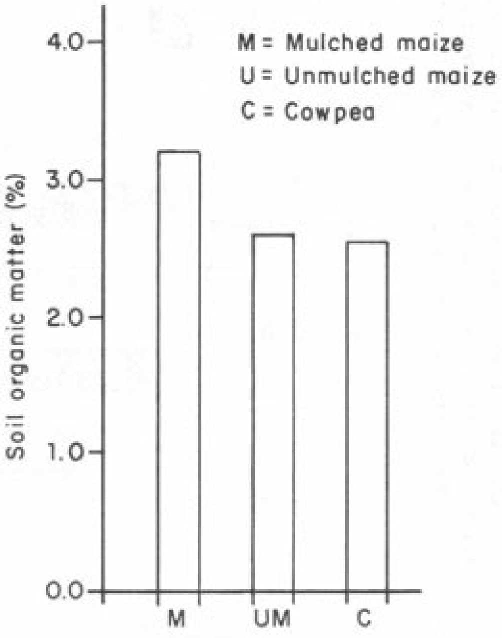


Fig. 5b Effect of different mulching practices on soil organic matter

6. TILLAGE PRACTICES INCLUDING MINIMUM AND ZERO TILLAGE WITH HEAVY EQUIPMENT

One of the major constraints to continuous cultivation is soil erosion. There are arguments for and against the use of heavy equipment in the tropics. The use of heavy equipment results in destruction of soil structure thereby increasing soil erosion. Under intensive continuous land use, intensive tillage operations are often carried out. After clearing, the uprooting of trees and burning of the vegetation exposes the soil to sun and rain. Some loss in structure occurs as a result of battering of rain drops and there is a rapid organic matter decomposition in the surface layer causing the soil aggregates to break down.

Douglas (1976), who worked on the effect of different types of tillage practices on the roughness of soil surface, reported that with continuous mixing of the soil by tillage operations, the subsoil loses its structure and its stabilizing properties such as soil colloids, organic matter and higher porosity. He compared the use of several types of equipment such as disc harrow, rotavator and mould board plough and concluded that the more intensive the tillage, the greater the destruction of soil structure and decomposition of the organic residue. Zero tillage produced a rougher soil surface than intensive tillage.

Tillage practices and time have been found to affect the bulk density of the soil (Table 6). The more intensive the tillage practice, the higher the bulk density. Discing, harrowing and ploughing with a tractor have a compacting effect on the soil, which affects the seed bed, and if this continues soil structure below the plough layer is disrupted.

Experiments conducted at the IITA, Ibadan, have shown that nutrient losses from surface runoff water are negligible compared with the loss of nutrient and organic matter in eroded soil. In these tropical soils, the leaching losses of nutrients by percolating water are more serious than the loss by runoff water. Runoff losses from bush fallow plots have been found to be about 1 - 2% of the rains received as compared to maximum of 29% from cleared land.

Loss of surface soil and nutrient can result in significant yield reductions particularly on soil with shallow surface soil horizon. The effect of artificial removal of surface soil on yield reduction of maize and cowpea for the Egbeda soil series has shown a loss of 2.5 cm of surface soil resulting in a yield reduction of 40% for maize and 50% for cowpea.

As for the savanna zone, erosion is probably more serious than in the lowland forests. The preparatory cultivation before each crop season and the hoeing to control weed during the growth of crop tend to destroy aggregates and seal the soil surface, resulting in increased runoff.

6.1 Soil Physical Properties

Agboola and Corey (1973), have pointed out that at the onset of the growing period after fallowing, the nutrients are all at their peak, but as cultivation continues, the nutrient elements tend to leach out.

At Badeku, a village about 15 km south east of Ibadan, an experiment was started in 1970 on a five hectare cooperative farm to improve the cultural practices of the local farmers. There was underbrushing and the tops of the small trees were cut, but the big trees and the oil palms were left. There was neither burning nor tillage. The soil was moderately sandy. Maize was planted at a density of 17 500 plants per hectare. Planting was done by the cooperators. Fertilizer was banded, using the native hoe to make a groove 15 cm away from the plant, and 7.5 - 10 cm deep. Table 7 reports the changes in the soil nutrient status during nine growing

Table 6

THE EFFECT OF TILLAGE PRACTICES ON SOIL BULK DENSITY

Months	Sites	Years	Soil Depth (cm)							EMS	LSD
				A	B	C	D	E	F		
April	I	1973	5 - 10	1.36	1.52	1.29	1.44	1.31	1.38	.004	.109
		1974	5 - 10	1.36	1.52	1.29	1.43	1.32	1.37	.012	. 20
		1974	20 - 25	1.60	1.51	1.53	1.57	1.56	1.56		
		1975	5 - 10	1.32	1.33	1.36	1.32	1.32	1.34	.0023	-
	III	1975	5 - 10	1.35	1.31	1.33	1.35	1.35	1.36		
May	I	1974	5 - 10	1.42	1.53	1.44	1.45	1.47	1.45	.014	-
		1975	5 - 10	1.33	1.45	1.37	1.36	1.34	1.30	.020	-
		1975	20 - 25	1.41	1.50	1.55	1.51	1.53	1.56		
	II	1974	5 - 10	1.49	1.45	1.44	1.47	1.45	1.46	.004	-
	III	1974	5 - 10	1.55	1.62	1.63	1.62	1.53	1.52	.012	-
		1975	5 - 10	1.57	1.61	1.60	1.62	1.62	1.63	.007	
		1975	20 - 25	1.68	1.72	1.69	1.71	1.69	1.70	.008	
June	I	1973	5 - 10	1.42	1.55	1.43	1.51	1.48	1.46	.0021	-
		1973	20 - 25	1.53	1.69	1.67	1.61	1.46	1.57	. 07	-
		1974	5 - 10	1.49	1.56	1.53	1.54	1.47	1.52	.007	-
		1975	5 - 10	1.42	1.62	1.51	1.56	1.45	1.48		-
		1975	20 - 25	1.44	1.50	1.54	1.56	1.56	1.56		-
	II	1974	5 - 10	1.59	1.63	1.58	1.61	1.54	1.54	.004	-
	III	1975	5 - 10	1.56	1.58	1.60	1.59	1.53	1.53	.009	-
July		1973	5 - 10	1.48	1.59	1.54	1.60	1.53	1.54	.006	-
		1974	5 - 10	1.56	1.66	1.65	1.56	1.65	1.56	.014	-
		1975	5 - 10	1.51	1.68	1.59	1.60	1.52	1.58	.010	-
		1975	20 - 25	1.64	1.75	1.65	1.67	1.65	1.70		-
	III	1974	5 - 10	1.74	1.69	1.60	1.69	1.68	1.63	.017	-
		1975	5 - 10	1.62	1.64	1.64	1.63	1.63	1.58	.011	-

Table 7 EFFECT OF ZERO TILLAGE PRACTICE (USING NO PLOUGH) ON SOIL NUTRIENT STATUS AT BADEKU VILLAGE

Sample	pH	% Org. Carbon	% Total N	Available P (ppm)	C:N Ratio	Ca meq/ 100g	Mg meq/ 100g	K meq/ 100g	Ca:Mg:K Ratio	Extract-able Mn ppm	Extract-able Zn ppm	% Sand	% Silt	% Clay	Yield ton/ha
Initial	6.45	1.30	0.014	7.5	18:1	3.5	0.5	0.166	23:3:1	0.1	0.10	90	6	4	1.6
After 6 Crops of Maize	5.63	1.89	0.116	120	16:1	4.3	0.9	0.537	14:3:1	7	2.1	84	11	5	1.5
After 7 Crops of Maize	5.89	1.70	0.137	42	12:1	3.3	0.3	0.118	3:3:1	Nil	0.08	85	22	4	1.4
After 9 Crops of Maize	6.22	1.77	0.046	37	38:1	2.7	0.2	0.148	18:1:1	Nil	1.0	90	7	3	1.4

seasons of zero tillage with little or no soil exposure. The results indicate that high yields could be maintained but micronutrients will now be required to maintain the high yield.

Tillage operations also lead to loss of organic matter. In an experiment conducted by Agboola, he found that total N reduction varied from 500 kg/ha to 1 000 kg/ha during four growing seasons. The application of fertilizer appeared to increase the rate of total nitrogen decline, (Fig. 6). During each growing season, there was an average of about 5% reduction of total nitrogen, except under continuous maize cropping with fertilizer and no legume which lost about 7% total N during each growing season. Douglas (1976) found that after four seasons his zero tillage treatment had the highest nitrogen values of 1 043 kg/ha as compared to an average of 919.7 kg/ha for tilled plots.

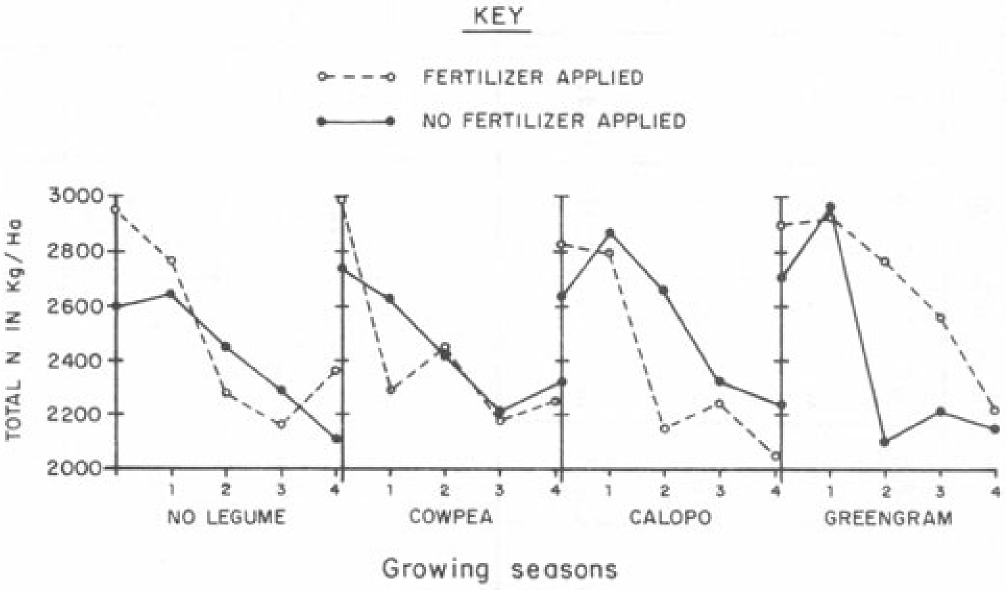


Fig. 6 Influence of legume intercrops and fertilizer treatment on total nitrogen under continuous maize

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Paper 6

CROP RESIDUE MANAGEMENT AND SOIL PRODUCTIVITY IN SAVANNA AREAS OF NIGERIA

V. Balasubramanian and L.A. Nnadi [1]

1. INTRODUCTION

Traditional cropping systems based on short cropping cycles and long fallow periods maintained soil fertility at a low but adequate level for the non-intensive agriculture of past years. With the progressive intensification of cropping and the consequent reduction in the fallow period (fallowing is completely abandoned in areas around big cities), soils in the savanna area are experiencing greater strain in supplying the nutrients required by the crops.

In the improved farming systems, soils should be compensated for the nutrients removed by the crops. It is estimated for the year 1970-71, that crops in the Nigerian savanna area removed as much as 0.52 million tonnes of N, 0.07 of P, 0.60 of K, 0.15 of Ca, 0.08 of Mg and 0.06 of S (Table 1). Only a portion of the absorbed nutrients is contained in the grains, nuts, tubers and other economic produce. Significant but variable amounts of plant nutrients are present in the crop residues which are disposed of in different ways. Estimates reveal that 24-53% of N, 21-62% of P, 80-93% of K, 77-99% of Ca, 48-93% of Mg and 43-75% of S absorbed into the tops are retained in the above-ground residues (Table 2). Crop residues are thus valuable sources of plant nutrients. As compared to inorganic fertilizers, organic residues are bulky and low in nutrient content; but unlike fertilizers, they are multinutrient sources, carrying almost all the elements required for plant growth.

In the developing world, crop residues are thought of as assets rather than as wastes. They are utilized in many ways (for fuel, cattle feed, domestic and manuring purposes). If the residues are returned to the soil after their potential for primary use is exhausted, at least part of the nutrients removed from the soil will be returned and the rate of decline of soil fertility can be slowed down. This report describes how the crop residues are utilized in the savanna area of Nigeria and how it affects soil fertility and crop yields.

2. TYPES OF CROP RESIDUES AVAILABLE

Mostly cereal (millet, sorghum, maize, wheat, and upland rice) straws, haulms and shells of legumes (groundnuts, cowpeas, bambarra groundnuts) and stalks of cotton and other fibre crops are the major sources of crop residues available in the northern part of Nigeria. A small amount of vegetable and sugarcane residues is produced and incorporated into the soil in the low land or 'fadama' areas. Not much residue is generated from root crops such as cassava and yam. Cassava stems are used as planting material while the amount of leafy residues obtained from yam is insignificant in this part of the world. Residues from banana, citrus, mango and other orchard crops are of local importance.

3. NUTRIENT COMPOSITION OF CROP RESIDUES

Concentrations of major and secondary elements in various crop residues are shown in Table 3. Plant residues in general are rich in K, low in P, poor to medium rich in N; contents of secondary elements are highly variable. It is also clear from this table that legume residues are richer in nutrients, particularly N, Ca, and Mg, than cereal straws. Leaves contain more nutrients than stems which contain slightly more nutrients than roots.

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Table 1 NUTRIENT REMOVAL BY CROPS IN THE SAVANNA AREA FOR THE YEAR 1970-71
(values in thousand tonnes)

Crop	N	P	K	Ca	Mg	S
Millet	141.28	16.73	223.88	41.57	29.44	23.04
Sorghum	131.14	19.10	179.90	24.50	19.20	17.31
Maize	16.26	2.03	12.56	2.73	1.39	2.00
Wheat	0.50	0.10	0.38	0.05	0.04	-
Rice	2.34	0.50	2.01	0.34	0.29	-
Groundnut	124.58	14.93	79.28	20.03	17.07	11.53
Cowpea	72.52	8.81	68.50	45.95	10.12	-
Cotton	32.53	7.01	30.04	13.30	2.79	-
Total	521.15	69.21	596.55	148.47	80.34	53.88

Table 2 NUTRIENTS PRESENT IN RESIDUE AS A PERCENTAGE OF THE
TOTAL IN TOPS (SHOOTS)

Crop	N	P	K	Ca	Mg	S
Millet	53	62	92	97	90	75
Sorghum	49	58	93	95	75	64
Maize	31	32	82	95	57	43
Wheat	24	21	90	80	51	-
Rice	32	24	86	77	48	-
Groundnut	40	41	80	95	77	55
Cowpeas	50	43	82	98	82	-
Cotton	43	40	81	99	93	-
Mean	40	40	86	92	72	59

Table 3 MEAN NUTRIENT CONCENTRATION OF CROP RESIDUES (%)

Crop and Plant part	N	P	K	Ca	Mg	S
Millet - Stover 1/	0.65	0.09	1.82	0.35	0.23	0.15
Sorghum - Stover 2/	0.58	0.10	1.51	0.21	0.13	0.10
Maize - Stover 2/	0.70	0.14	1.43	0.36	0.11	0.12
Wheat - Straw 2/	0.62	0.12	1.72	0.27	0.15	0.12
Rice - Straw 3/	0.58	0.13	1.33	0.20	0.11	-
Groundnut - Leaves 2/	2.56	0.17	2.11	1.98	0.68	-
- Stems	1.17	0.14	2.20	0.92	0.50	-
- Roots	1.18	0.07	1.28	0.65	0.34	-
- Haulms	1.40	0.21	1.80	0.90	0.50	0.18
- Shells	1.00	0.06	0.90	0.25	0.10	0.10
Cowpea - Leaves 1/	1.99	0.19	2.20	3.16	0.46	-
- Stems	1.07	0.14	2.54	0.69	0.25	-
- Roots	1.06	0.12	1.50	0.37	0.24	-
Cotton - Stalks 2/ and Leaves	1.33	0.27	2.35	1.27	0.25	-

Source: 1/ Nnadi et al, 1977.
2/ Author's own analytical data unpublished.
3/ Charreau, 1974.

Table 4 ESTIMATED AREA AND PRODUCTION OF GRAINS AND RESIDUES IN NORTHERN NIGERIA FOR THE YEAR 1970-1971

Crop	Area 1/ M. hectares	Grain 1/ Production M. tonnes	Grain/ Residue ratio	Residue Production M. tonnes
Millet	4.97	3.11	0.27	11.52
Sorghum	5.62	3.99	0.36	11.08
Maize	0.67	0.54	0.75	0.72
Wheat	0.01	0.02	1.00	0.02
Rice	0.16	0.13	1.00	0.13
Groundnut	1.82	1.54	0.34	4.53
Cowpea	3.69	0.83	0.35	2.37
Cotton	0.70	0.70 2/	0.67	1.04
Total	17.64	10.86	-	31.41

1/ Data adopted from "Rural Economic Survey of Nigeria: consolidated results of crop estimation surveys, 1968-69, 1969-70, 1970-71." Federal Office of Statistics, Lagos (1972).

2/ Seed cotton yield (and not lint weight).

Table 5

ESTIMATED AMOUNT OF NUTRIENTS CONTAINED IN
CROP RESIDUES PRODUCED IN 1970-71
(values in thousand tonnes)

Crop	N	P	K	Ca	Mg	S
Millet	74.88	10.37	209.66	40.32	26.50	17.28
Sorghum	64.26	11.08	167.31	23.27	14.40	11.08
Maize	5.04	0.65	10.30	2.59	0.79	0.86
Wheat	0.12	0.02	0.34	0.05	0.03	0.02
Rice	0.75	0.12	1.73	0.26	0.14	-
Groundnut 1/	49.83	6.12	63.42	19.03	13.14	6.34
Cowpea	36.26	3.79	56.17	45.03	8.30	-
Cotton 2/	13.83	2.81	24.44	13.21	2.60	-
Total	244.97	34.96	533.37	143.76	65.90	35.58

1/ Groundnut residues include both haulms and shells.
2/ Cotton residues include only stalks and leaves.

Each of these methods are discussed in greater detail in the following sections. In these discussions, examples are quoted from Nigerian Savanna; wherever local data are not available, works from nearby West African countries and outside West Africa are included to illustrate the point in discussion.

6.1 Fuel

Dry stover of millet, maize and sorghum and stalks of cotton are burnt as domestic fuel for cooking. In the savanna area, trees are few and there is always a scarcity of firewood. This is particularly true in the Sudan and Sahel Savanna Zones and the northern border of Guinea Savanna where vegetation is very sparse. In the absence of alternate energy sources, it is very difficult to stop the practice of burning crop residues for domestic fuel. Establishment of tree groves or plantations of quick growing trees like Eucalyptus, Casuarina, Margosa, etc., will not only serve as wind breaks but also provide the much needed firewood in rural areas. Also attempts should be made by Government to supply cheap (and subsidized) fuel (e.g. kerosene) for domestic use in villages. Wherever the residues are burnt as fuel, at least the ash should be returned to the field so that nutrient cations will be restored to the soil.

6.2 Field Burning

Annual burning of fields and fallows in the dry season is a common practice in the savanna area. Dry weeds and residues are collected into heaps at several places and burned. This is done to clear the land of all the weeds and other bush growth in order to facilitate cultivation. Such bush fires are at times uncontrollable and they may even threaten village settlements. In the absence of farm power to do the ploughing and/or primary tillage prior to planting, burning is the only way to clear the land for cultivation by hoe.

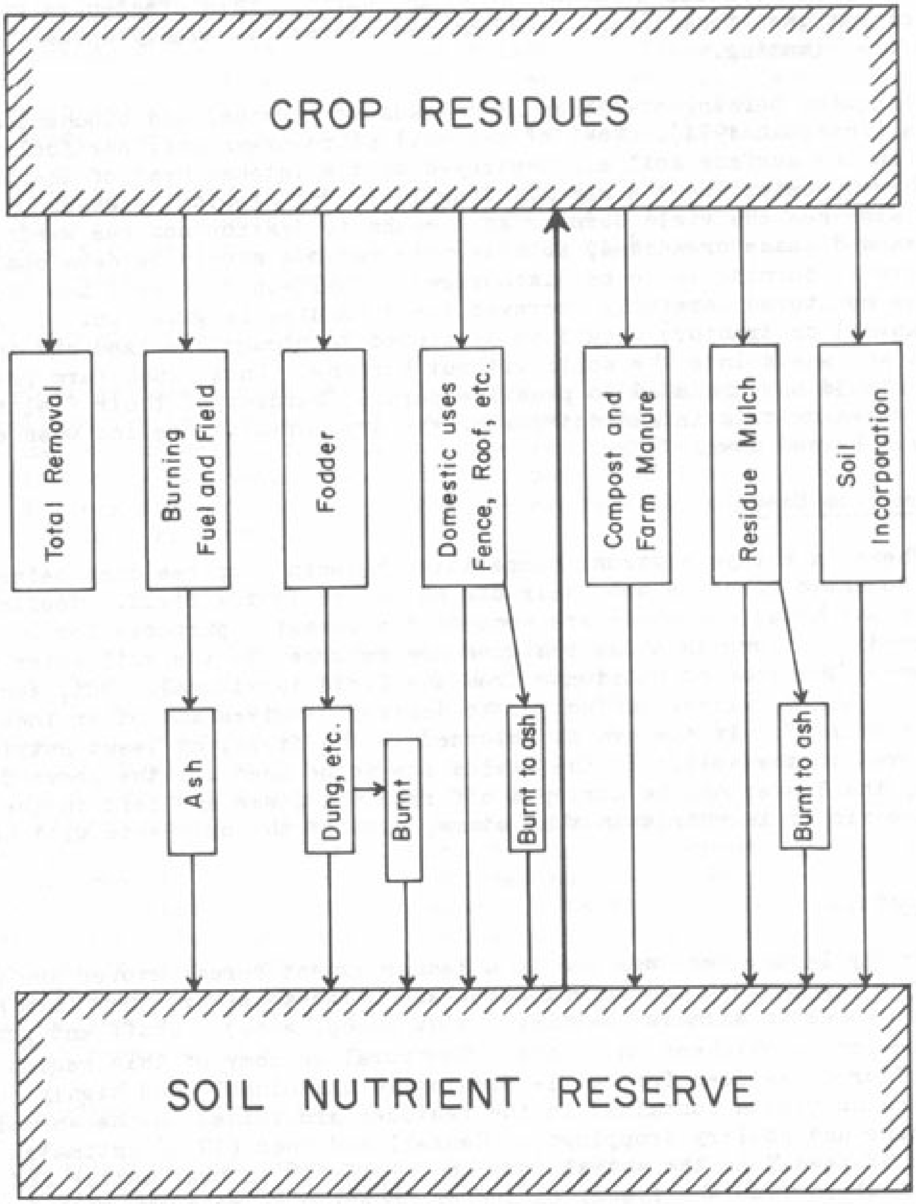

Fig. 1 Nutrient recycling between crop residues and soil

Burning of organic residues either in the field or as fuel results in considerable loss of carbon and nutrients in organic form, viz, N and S. Charreau (1974) estimates that 20–40 kg/ha of N and 5–10 kg/ha of S are lost by annual burning; this accounts for the general lack of C, N and S in savanna soils. Loss of P by burning is quite low. Nutrient cations and trace elements are not lost by burning as they are retained in the left-over ash. However, the ash is concentrated at isolated spots where the residues were collected and burnt. This creates an unequal distribution of nutrient ions in the field unless the ash is evenly spread over the entire area before planting.

Frequent burning of fields also leads to physical and biochemical degradation of soils (Charreau 1974). Most of the soil micro-organisms, particularly Rhizobia, present in the surface soil are destroyed by the intense heat of the bush or field fire, thereby upsetting the already fragile microbiological make-up of the soil. Farmers also see the field burning as a means to destroy noxious weeds, harmful insects and disease organisms, so alternate methods should be developed to control crop pests if burning is to be discouraged. Build-up of insect and disease pests should be monitored carefully wherever field burning is given up. In addition, farm power (animal or tractor) should be developed to plough the land and to incorporate residues and weeds into the soils without burning. Until such farm power is developed, farmers should be pursuaded to practice partial burning of their fields just before the rainy season sets in and not during the dry harmattan period when every twig is completely burned down.

6.3 Other Domestic Uses

There is always a strong competition between crop residues being used for various domestic purposes and their use as manure in the field. Roofing and fencing of fields and house compounds are some of the domestic purposes for which cereal stover is employed. As long as these residues are returned to the soil after their primary use is over, the loss of nutrients from the field is minimal. But, such materials are usually burnt, either as fuel or to destroy termites and other insects attacking the fence or roof. If the ash is returned to the field, at least nutrient cations are restored to the soil. If the stalks are to be used for the above domestic purposes, the leaves can be stripped off from the stems and left in the field. Since leaves are richer in nutrients than stems, part of the nutrients will be returned to the soil.

6.4 Cattle Feed

Mostly legume residues and to a lesser extent cereal stover are used as cattle feed. When legume tops and cereal straw are mixed together, they form a nutritious fodder for domestic animals (cattle, goats, sheep, etc.). Chaff and pest infected grains are fed to chickens and ducks. The rural economy of this region is such that the use of crop residues for cattle feeding is unavoidable and highly justifiable. Most of the nutrients contained in the residues are voided in the animal excreta (urine, dung and poultry droppings). Henzell and Ross (1973) estimated that the retention of feed N in the animal body is only 4–10% in beef cattle and 13–28% in milking cattle. Thus the faecal wastes of domestic animals are rich in nutrients derived from crop residues and they should be returned to the field if we have to restore partially the nutrients removed from the soil.

Since cattle rearers and farmers belong to distinctly different tribes in Nigeria, close cooperation is necessary between these groups of people to use the crop residues as cattle feed and to return the animal voidings to the field. At present, such complementary roles between farmers and cattle men are extremely limited in the Nigerian Savanna. The nutrients gathered in the diet of animals grazing haphazardly are scattered over a large area of land during their migrations. To obtain the combined use of residues for milk, meat and manure production, mixed farming should be practised by each and every farmer.

6.5 Composting

Organic residues, when composted, undergo decomposition by the digestive action of bacteria, fungi and other soil microfauna. Within two or three months, a dark, friable material rich in humus is produced. Most of the organic N, S and P are converted into plant-available inorganic forms. The C/N ratio decreases and pH increases. Well decomposed compost is a good source of available nutrients which are supplied to the plants slowly and gradually. It can be applied to the soil just before planting without fear of N immobilization. Since composting reduces the bulk and volume of the residues, it facilitates easy handling. Certain organic constituents present in the compost act as chelating agents and help in the absorption of certain trace elements. Composts are good for vegetable and kitchen gardens.

Composting is not a common practice in the savanna region of Nigeria. This is because of lack of water in the dry zones, high labour requirement for processing and transport (Charreau, 1974), limited supply of residues, and farmers' ignorance of benefits accruing from composts.

6.6 Use as Component of Farm Manure

Wherever domestic animals are raised by farmers themselves as in mixed farming, crop residues can be used as fodder as well as bedding material. The urine soaked organic wastes and animal excreta can be mixed together with fresh crop residues unsuitable for use as animal feed and then converted into farm manure. Since mixed farming is very uncommon in the savanna zones, use of crop wastes as a component of farm manure is a rare practice.

6.7 Mulching with Crop Residues

Surface mulch with crop residues is not a common practice in the semi-dry savanna areas except in isolated pockets (fadamas) where vegetables and sugarcane are grown continuously throughout the year with the help of small irrigation facilities. In fadamas, the soil is well protected against erosion as well as enriched with organic matter. Erosion hazards in upland soils are high due to wind in the dry season and water (torrential rains) in the wet season. Residue mulch, if practised here, would help to minimize wind and water erosion of coarse and unstable surface soils by directly controlling wind-blow and decreasing the effect of rain drop and surface run-off (Nnadi and Balasubramanian 1977). Organic mulches are invariably attacked by termites in the dry season and this is a big deterrent against mulching in upland soils. In places where surface mulch is practised in small scale, the residues are usually burnt at the end of the dry season to kill all the termites. Even though erosion is reduced by such practices, organic matter is destroyed by fire and only cations are added to the soil through ash. So the organic matter content of the soil remains low all the time.

6.8 Soil Incorporation of Residues

In all the above methods of residue disposal only a part of the nutrients in crop residues is restored to the soil. But residue incorporation, on the contrary, ensures complete return of nutrients contained in the crop wastes to the soil. In the savanna area, only an incipient incorporation of crop residues and weeds is noticed when new ridges are formed by splitting the old ones. The organic remnants lying in the old furrows are buried underneath the soil collected to form the new ridges which are sited over old furrows. Because of the lack of draught (animal or tractor) power in rural farms, regular and thorough mixing of organic wastes with the soil either by ploughing or by surface tillage is uncommon in the savanna zone. Commercial and government farms, which have the access to tractor power, can lead the way in practising residue incorporation in this region.

Incorporation of carbonaceous residues low in N may immobilize the available N in soils and affect the early plant growth, therefore enough N fertilizer should be applied to compensate for the N immobilization caused by the decomposing residues and to meet the plant requirements. If residues are incorporated immediately after harvesting, it will not only facilitate partial decomposition of the wastes but also conserve the soil moisture stored in the profile by providing a dust mulch on the surface (Charreau 1974). Since the residues are partially decomposed prior to planting of the succeeding crop, its initial growth will be less affected by N immobilization. After harvest ploughing also facilitates early planting due to reduced pre-plant tillage operations. Long season crops (cotton and sorghum) and late harvested cowpeas pose problems in ploughing in of residues at the end of the growing season since the soil is very dry and hard to plough at the time harvesting is completed for these crops. Direct mixing of crop residues in the field itself requires no transport from one place to another. It has also been demonstrated that direct ploughing in of straw along with P and Ca fertilizers stimulates non-symbiotic N fixation in the soil (Deavin 1974; and Primavesi and Primavesi 1974).

7. EFFECT OF RESIDUE MANAGEMENT ON SOIL FERTILITY

7.1 Complete Removal of Residues

This practice virtually depletes the soil of all the nutrients, particularly cations. The amounts of nutrients removed from the soil by various crops when no residues except roots are retained in the field are shown in Table 1. Of these nutrients, only N depletion can be reduced by growing leguminous crops which may add some symbiotically fixed N to the soil. Natural addition of nutrients through rainfall, harmattan dust, etc., is very low (Jones and Bromfield 1970; Bromfield 1974 a,b) and cannot compensate for crop removal.

In addition to nutrients, organic matter content also decreases drastically when residues are totally transported from the field (Jones 1976; Charreau 1974). Decrease in organic matter content leads to physical, chemical and biological deterioration of soils. Organic matter stabilizes soil aggregates formed by other physical forces (Allison 1973) and hence any decrease in the former results in the degradation of soil structure. Other physical effects of organic matter depletion are increased runoff losses and erosion, reduced soil moisture retention (Charreau 1974) and increased soil compaction (Greenland 1972). Since soil organic matter accounts for 60-80% of the cation exchange capacity of savanna soils (Kadeba and Benjaminsen 1976), any reduction in the former will lead to decreases in exchange capacity and cation retention. Work at Samaru has shown that the complete removal of crop residues results in a drastic decrease in topsoil exchangeable K and Mg (Table 6). Cation depletion leads to progressive soil acidification which is further intensified by N fertilization without organic matter incorporation. Acidification and soil compaction in soils devoid of organic matter have rendered the growth of cereal crops impossible in a section of the research farm in Kano. Sandy soils developed on aeolian deposits are particularly vulnerable and they degrade very fast if enough organic matter is not added to the soil.

7.2 Partial Return of Residues

All the residue management practices except soil incorporation achieve only partial return of harvest residues to the soil. When used as cattle feed, part of the nutrients of the fodder is ingested into the animal body or products (milk, meat, egg, etc.). If the wastes are composted, some of the nutrients are lost during processing and transport. When the residues are burnt, most of N and S and part of the P are lost; cations are returned to the soil in the form of ash. The effects of the above practices on soil are more towards that of incorporation than that of total removal. Burning does not allow the build-up of organic matter in the soil while

Table 6 EFFECT OF RESIDUE TREATMENTS ON CHANGE IN TOPSOIL CHEMICAL PROPERTIES 1971-74 (after Jones 1976)

Treatment	Change in						
	Organic (%)	Total N(%)	pH	Exchangeable ions (meq/100g)			
				Ca	Mg	K	Total
Burn	−0.022	−0.000	−0.16	+0.01	−0.005	+0.007	+0.01
Incorporate	−0.003	+0.001	−0.33	+0.01	−0.005	−0.005	−0.01
Remove	−0.24	+0.000	−0.32	+0.03	−0.044	−0.085	−0.10
SE(±)	0.008	0.002	0.03	0.03	0.007	0.006	0.04

composts and farm manures help to increase the soil humus content. Addition of ash minimizes the fall in soil pH and exchangeable cation (Jones 1976). It has been reported by Jones (1971) that the mean soil carbon (0.82%) of plots that received 12.5 tonnes/hectare/year of farm manure for nearly 20 years is almost four times as great as the mean carbon content (0.22%) of soils in control plots. Continuous application of dung increased soil C, N, cation exchange capacity, exchangeable Ca and Mg and pH, and decreased soluble Al and Mn (Bache and Heathcote 1969).

It is common observation that the level of soil fertility decreases as the distance between the house compound and the field increases due to poor return of residues to the far off fields. Whatever residues are left over after meeting the domestic and cattle needs must be returned to the field if the rate of depletion of soil fertility is to be reduced.

Mixed and rotation cropping with legumes is a common practice in the Nigerian Savanna. It is very difficult to remove all the roots, nodules and nuts while harvesting groundnut and bambarra groundnut crops, especially when the harvest is delayed and carried out in the very dry period. In such cases, some of the symbiotically fixed N is left over in the soil even if the legume tops are transported from the field. Thus nutrients carried in subterranean plant parts (roots, nodules, etc.) help to maintain soil fertility in places where legumes are included in cropping systems.

7.3 Incorporation of Residues

This is the only practice which ensures complete return of residues to the soil. Incorporation greatly decreases the rate of drain of nutrients from the soil reserve. In addition, it induces beneficial changes in physical, chemical and biological properties of soils through the build-up of soil humus. Increased organic matter content results in better aggregation and structure, favourable soil moisture status and reduced runoff and erosion losses. Vegetative matter should be ploughed in rather than left on the surface as mulch to improve macrostructure in the light textured soils of the semi-dry savanna area (Charreau 1974). Straw and stover maintain the macrostructure better than other forms of organic matter (roots, composted straw, green manure, etc.). The claim that increased humus content in soils decreases soil compaction during dry seasons because the organic anions inactivate iron hydroxides which otherwise crystallize and harden ferrugenous soils (Greenland 1972) lacks experimental proof in semi-dry savanna soils.

High content of soil organic matter increases the exchange capacity and cation retention, reduces P fixation and acts as a source and sink for trace elements in soils. Mineralization of organic matter slowly and steadily releases the nutrients contained in the residues for use by crops. Very high increase in organic matter and soil nutrients as a result of return of millet residues to soil have been reported from Niger Republic (Pichot et al 1974). Incorporation of crop residues has been shown to maintain surface soil carbon and Mg and K at Samaru (Jones 1971 and 1976).

Soils rich in organic matter support a large population of soil microflora and fauna which are mostly beneficial to crop plants. For example, the number and activity of earth-worms are very high in garden and "fadama" soils where crop residues are incorporated into the soil. Organic matter, during decomposition provides the much needed energy and carbon for the active growth and multiplication of soil microbes. This might be the reason for the stimulation of non-symbiotic N fixation in soils treated with straw and P fertilizers (Deavin 1974; Primavesi and Primavesi 1974; MacRae and Castro 1967).

Pathogens are also stimulated along with other organisms by organic amendments; whether a diseased condition is initiated, increased or decreased then depends on the presence of a suitable host at the time, the status of antagonists, and the prevalent environmental conditions (Ayanaba and Okigbo 1975). Decomposing plant materials may produce phytotoxic substances (Linderman 1970; and Langdale 1970) but no information is available on such effects of organic residues in semi-dry soils of savanna.

8. EFFECT OF RESIDUE MANAGEMENT ON CROP YIELDS

The favourable changes produced in soil properties by the addition of organic matter through incorporation of residues, compost or ash improve soil fertility and increase crop yields. Unfortunately, most of the residue management trials have not been conducted long enough to prove unequivocally the beneficial effect or otherwise of organic additions. With short term trials, it has been shown that crop yields in general tend to be higher with "incorporate" and burn treatments as compared to total removal of organic residues (Table 7). This confirms the earlier observation of Heathcote (1969) that there was a general increase in crop yields from the addition of organic matter, especially when it was applied after burning (Table 8). Thus, data from both these experiments indicate that crop yields from "incorporate" and "burn" treatments are not so different. Increases in yields due to soil amendment with organic matter have been reported from other parts of West Africa (Charreau 1974; IITA 1973; Okigbo 1965).

Growing legumes in rotation with cereals always increases the yield of the latter. Even if the tops are transported from the field, cereal yields from previous legume plots are higher than those from previous sorghum or cottor plots as shown in Table 9 (IAR 1977; Jones 1974). Groundnuts and bambarra groundnuts seem to be better than cowpea in increasing the yield of the following cereal crop.

Table 7

EFFECT OF RESIDUE MANAGEMENT ON CROP YIELDS (at 135 kg N/ha level) UNDER CONTINUOUS CULTIVATION AT SAMARU, 1972 - 1976

Year	Crop	Yield (kg/ha) under		
		Burn	Incorporate	Remove
1972	Maize	4 207	4 172	4 523
1973	Millet	1 422	1 346	1 336
1974	Maize	3 577	3 695	3 293
1975	Millet	925	1066	985
1976	Maize	3 578	4 192	3 289
Mean	-	2 742	2 894	2 685

Table 8

CROP YIELDS AT DIFFERENT LEVELS OF ADDED ORGANIC MATTER AS SUCH AND AFTER BURNING (Heathcote 1969)

Year	Crop	Burning Treatment	Yield (kg/ha) with added O.M. at (t/ha)		
			0	2	4
1966	Sorghum	Unburned	833	962	1 027
		Burned	821	1 023	1 252
1967	Seed Cotton	Unburned	785	828	827
		Burned	751	932	1 077
1968	Maize	Unburned	956	1 057	1 238
		Burned	929	1 243	1 490

Table 9 EFFECT OF PREVIOUS CROP ON MAIZE YIELD AT SAMARU AND KADAWA (kg/ha)

Previous Crop	Samaru	Kadawa	
Cowpea - NEP 593	2 082	3 600	A
Cowpea - 556/2	1 083	3 493	
Cowpea - Ife Brown	1 167	3 330	
Bambarra Groundnut	2 678	3 332	
Sorghum	1 371	1 752	
LSD (P = 0.05)	594	601	
Cotton	4 806	-	B
Sorghum	4 142	-	
Groundnut	5 135	-	
Cowpea	4 369	-	
LSD (P = 0.05)	327	-	

NOTE: A = Maize yields without any added N fertilizer (IAR 1977).
B = Mean maize yields of different N levels (Jones 1974).

9. SUMMARY AND CONCLUSIONS

It is estimated that 31.4 million tonnes per annum of crop residues are produced in the Nigerian Savanna. The magnitude of nutrients contained in these residues is estimated to be 0.250 million tonnes for N, 0.035 for P, 0.533 for K, 0.144 for Ca, 0.066 for Mg and 0.036 for S. The amount of NPK nutrients available from residues is about 77 times as much as the NPK nutrients added through fertilizers in this area in 1970-71. Thus, crop residues represent a valuable source of plant nutrients and so they should be regarded as assets rather than as wastes.

Nutrient recycling takes place between crop residues and soil and the direction of flow of nutrients in this cycle is determined by the nature of crop residue disposal. Total removal of residues from the field adds no nutrients to the soil whereas ploughing in of crop wastes achieves considerable return of nutrients to the soil. The extent of loss of nutrients from residues used for other purposes (fuel, fodder, mulch, roofing, fencing, etc.) is highly variable and lies within the above two extremes of total removal and total incorporation.

Burning of residues, either in the field or as fuel results in considerable loss of carbon and nutrients in the organic form, viz, N and S. This accounts for the general lack of C, N and S in savanna soils. If the ash is returned to the field, it will restore the cations to the soil reserve and maintain soil pH. In addition to nutrient loss, recurrent field burning results in physical and biochemical degradation of soils. Provision of cheap, alternate energy sources for fuel and farm power to till the land for cultivation will discourage the farmers from resorting to destructive residue burning.

The combined use of residues for milk, meat and manure production is achieved when crop wastes (particularly legume residues) are fed to animals. Return of cattle dung and other animal wastes will restore part of the nutrients removed from the soil. Mixed farming is uncommon in the Nigerian Savanna because farmers and nomadic cattle men belong to distinct tribal groups and at present there is little cooperation between them. Thus, the recycling of residue nutrients through animals is restricted to goats and sheep in Nigeria.

Because of the dry climatic conditions and scarcity of water, the labour intensive process of composting residues is rarely practised in the savanna zone.

Residue mulching is not common in upland soils due to termite problems. Ploughing in of residues seems to be better than leaving trash on the soil surface as mulch until effective termite control is achieved. Addition of organic matter in any form increases soil C, N, cation exchange capacity, exchangeable cations and pH and decreases soluble Fe and Al. Organic amendments also improve the physical and biochemical properties of soils.

Proper utilization of crop residues not only helps in maintaining the soil nutrient status which ensures high crop yields, but also minimizes soil erosion, desert encroachment and environmental pollution.

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Paper 7

THE USE OF ORGANIC MATERIALS IN INCREASING CROP PRODUCTION IN AFRICA

C.S. Ofori [1]

1. INTRODUCTION

It is generally recognized that increased food production to feed the world's growing population cannot be met mainly through expansion of cultivable areas, but through intensification of agricultural productivity. This could hardly be achieved without, among other things, development and adoption of high yielding varieties, improved agronomic practices and the use of fertilizers.

Inorganic fertilizers, one of the important inputs for increased food production, are expensive and developing countries can hardly afford to meet the high costs. It is however, unrealistic for developing countries to depend solely on the use of organic materials to meet the nutrient requirements of crops cultivated. Certainly every effort should be made to use all available organic material on the farm for the maintenance of soil fertility but remembering that organic and inorganic fertilizers are complementary.

Cropping systems, technological level of production and management systems are important pre-requisites for any efficient use of organic fertilizers. Extensive research work on crop residue management, manuring with both solid and liquid (dung and slurry) has been carried out in temperate regions. Relatively few results are available in the tropics with the exception of extensive work in tropical Asia where manuring is a traditional practice.

Composting has been an important practice since ancient times in Asia but is relatively recent in some African countries. Its impact on agricultural production seems however to be limited by the economics of the system, particularly with the advent of mineral fertilizers which are higher in nutrients, thereby reducing considerably transportation costs.

The use of sewage sludge is gaining importance in agriculture, but the attendant problem of concentration of heavy metals at toxic levels and of other microelements in sludges from highly industrialized areas are still being investigated. At present, sludge is available only in few African cities but attention and consideration need to be given to its future use.

2. INCORPORATION OF CROP RESIDUE

The availability of crop residues as a source of organic material for the maintenance of soil fertility depends greatly on the cropping systems and rotations involved. Cropping systems with predominantly root and tuber crops have little to offer in the form of crop residues. Cereal and legume rotations are effective sources of residues to be incorporated into the soil. The inclusion of legumes, for example groundnuts, in the rotation could contribute N through the activities of nitrogen fixing bacteria, and the tops could also be used as feeds for livestock, consequently producing manure thus recycling the nutrients taken up from the soil. The incorporation of straw into the soil is not without its attendant problems. Due consideration should be given to the C/N ratio so as to avoid immobilization of soil N. Nagarajah

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and Amarasiri (1977) pointed out that immobilization of soil N, difficulties in tillage operations where straw is not incorporated into the soil and is undecomposed, and introduction of pests and diseases limit the use of rice straw in low land rice cultivation in Sri Lanka. Using maize straw together with inorganic fertilizers in Madagascar, Velly and Longueval (1976) found that the effect of the straw was evident after two years. They advocated the use of mineral N and straw as a satisfactory technique for improving the humic balance in tropical soils. Lands and De La (1975) suggested the application of 5–7 kg N/ton straw to avoid immobilization of soil N and prevention of toxic effects of reducing processes during decomposition. Jones (1976) reported results which showed that in continuously cropped savannah soils, incorporation of millet and maize residues produced no significant increase in the organic carbon content. Similar results with straw were reported by Rauhe (1969). Chater and Gasser (1970) on the other hand, reported a reduction of the loss of organic C and total N when straw was incorporated in contrast to the treatments without addition of any organic material. Incorporation of 5–10 t/ha of crushed groundnut shells in Niger and Senegal was reported to have markedly increased subsequent yields of groundnuts and millet (Gillier 1964; Lienart and Nabos 1967).

It would appear that the beneficial effect of residue incorporation on crop yield might be due to both physical and chemical effects on the soil. Improvement in pore volume resulting in greater rooting volume and proliferation as well as better utilization of water due to improved infiltration are some of the physical effects. The main chemical effect is the release of mineral nutrients on decomposition, particularly where the C/N ratio is favourable and the incorporation takes place well before the sowing of the crop. Results of Rizk et al (1967) indicate no depression in crop yield provided the residues were applied 2–6 weeks before sowing and ample moisture is present to promote decomposition of the organic matter. Skarda (1970) showed that straw balanced with mineral N had similar effects to farm yard manure on crop yield.

3. BURNING OF CROP RESIDUE

There are arguments for and against the practice of burning crop residue on the farm. Where incorporation is not possible because of technological limitations (farm implements employed), and mulching impracticable because of limited quantities involved, burning ensures at least the return of some of the nutrients to the soil. Secondly, burning destroys some of the pests that might have built up in the residue. There are indications that burning of crop residue does not significantly affect the soil organic C per se, but this in no way justifies the practice as in any case some nutrients as well as the beneficial physical and physico-chemical effects on the soil are lost in the process.

Burning of plant residues liberates P as H_2PO_4 which afterwards forms Ca, Fe and Al-phosphates in the soil (Fassbender 1975). A significant increase in water soluble cations and a decrease in their reserves as exchangeable cations is obtained. This might partly explain a beneficial effect on the succeeding crop yields but a rapid decline in subsequent yields if fertilizers are not applied. Heathcote (1970) obtained results which showed significantly higher yields of sorghum, cotton and maize after burning rather than incorporating mature bush grass on experimental plots. Charreau and Poulain (1964) on the other hand found incorporation of herbaceous fallow more beneficial than when burned (Table 1).

Table 1 THE EFFECT OF FALLOW INCORPORATION ON THE YIELD OF MILLET (kg/ha)

Fallow treatment	No Fertilizer	NPK applied
Burned	912	1 565
Incorporated	1 244	1 809

An improvement of the soil physical conditions with consequent improved rooting medium coupled with mineralization might account for this.

4. USE OF FARMYARD MANURE

Due to restrictions imposed by the tsetse-fly in large parts of the forest areas in Africa, animal husbandry is restricted to the savannah areas. Dung production is nevertheless limited because of the semi-nomadic husbandry practices and the material is often of low quality since very little attention is paid to its storage.

Considerable research work however, has been carried out using farmyard manure to increase crop yield as well as to maintain soil fertility in Africa. The effect of farmyard manure on soil pH has been reported by several workers (Djokoto and Stephens 1961; Ofori and Potakey 1965; Dupont de Dinechin 1967; Pieri 1971; Primavesi 1968). Increase in exchangeable cations as well as organic N and available P have also been obtained on soils receiving large applications of manure (Olsen et al 1970). The beneficial effects of manure on crop yields obtained in most parts of Africa seemed to be mainly due to its mineral composition (Heathcote 1970; Stephens 1969). The constraint to its use, is that quantities required to make any significant impact are too high and often unattainable on most of the small farm holdings. However, responses to low rates of application have been recorded by Greenwood (1958) and Nye (1953). A good management practice therefore will be to supplement the available manure with inorganic fertilizers. Farmyard manure has a positive effect on the availability of P to the crop. Its beneficial effect on the availability of P is attributed mainly to (i) organic colloids preventing soluble P from coming into contact with active Al and Fe; (ii) the CO_2 produced through the decomposition of organic material dissolves some P material or ties up active Fe; (iii) organic phosphates formed are less firmly fixed by the soil and (iv) the mineralization of organic phosphorus by bacteria.

Datta and Goswami (1962) in India, reported increased uptake of P on four soils to which farmyard manure was applied in their experiments, the figures are given in Table 2.

Manure applications may not fully benefit a short season crop if the application is shortly before cropping. Undoubtedly, the decomposition rate under tropical conditions is several times that under temperate conditions. Fuches et al (1970) suggested that when applying manure with mineral fertilizers, nutrients from the latter will enhance the establishment of the crop whilst those resulting from mineralization of the organic manure will promote yield components, such as tillering grain/ear and 1 000-grain weight, that develop later in the season. The N from the mineral fraction of the dung is often too low, especially when the product is poorly stored, to support vigorous growth. The major source of N therefore is from the organic N. Ansorge (1968) observed that straw supplemented with N produced the same yield increase as dung.

Table 2 EFFECTS OF FARMYARD MANURE ON THE AVAILABILITY OF P

Farmyard manure	Alluvial Soil		Black Soil		Red Soil		Calc. Soil	
t/ha	Av. P_2O_5 uptake kg/ha		Av. P_2O_5 uptake kg/ha		Av. P_2O_5 uptake kg/ha		Av. P_2O_5 uptake kg/ha	
0	22	4.79	44	1.90	110	0.57	5.52	1.32
24.7	111	8.02	80	4.35	120	1.44	91	7.53
49.4	41	10.04	95	8.31	166	2.43	127	11.43

Analysis of farmyard manure: 0.24% P_2O_5, 14% C and 0.92% N.

On direct physical effects of dung on soils, only scanty information exists. Ermich and Drabner (1969) obtained results showing an improvement in pore volume and aeration. They also found that density of soil and shear strength were slightly reduced. Dung was found in this experiment to be more effective than straw.

5. GREEN MANURING

The commonly held view that green manuring under tropical conditions would increase soil organic matter has not been substantiated experimentally. Primavesi (1968) pointed out that due to its narrow C:N ratio which is approximately 4:1, green manure does not contribute to the soil humus. It is, however, an important source of energy to the soil micro-organisms (Russel 1961). Its main advantage seems to lie in its rapid decomposition releasing nutrients to the succeeding crop, as well as contributing N through fixation in the case of legumes. Haylett (1961), reviewing the effect of green manures on crop yields in South Africa, concluded that the beneficial effects are temporary, lasting for one or two crops only.

On the sandy soils in Senegal, Charreau and Nicou (1971) reported an improvement in soil structure by incorporation of a green manure crop. Morel and Quantin (1972) in the Central African Empire, however, observed no significant improvement on soil physico-chemical characteristics.

Green manuring seems to offer little advantage to the small farmer in the improvement and maintenance of soil fertility. First of all, it is a "crop" that he grows without any cash return; secondly, he often lacks the technology for easy incorporation into the soil since his implements are simple. This basic requirement could be met under "semi-intensive" agriculture where animal traction is available. It must also be stressed that production of a good crop of green manure in most of these areas on the continent will require the application of some form of fertilizer - a practice which the small farmer can hardly afford.

6. MULCHES AND COVER CROPS

Extensive work has been carried out in tropical areas on the use of mulches in soil management. Aside from the release of nutrients on decomposition, mulching is an efficient practice in reducing soil erosion. The crop residue acts as an energy dissipator which absorbs the raindrop impact and prevents dispersal of the soil aggregates (Okigbo and Lal 1976). In addition to this physical effect, the mulch contributes to the maintenance of biological activity of soil fauna at a level equivalent to that under natural vegetation, thus providing additional pores for water conduction (op. cit.).

The role of mulch in increasing soil productivity will be dealt with in a separate paper at this meeting.

Cover crops play an important role in erosion control, maintenance of soil temperature, improvement of soil structure, tilth, air filtration rate and weed control. Leguminous cover may have the added advantage of contributing fixed N. In both plantation and food farming the use of cover crops should be actively encouraged. Okigbo and Lal (1976) stressed the significant differences in crop yield that exist depending on the nature of cover crop grown. These workers found crops grown in sods of leguminous creepers such as Stylosanthes gracilis, Centrosema pubescens and Pueraria phaseoloides yielded better than others. The use of living mulch such as the perennial peanut Arachis glabrater in cropping systems has attracted attention in recent research programmes, especially in CIAT, Columbia. Such experiments, if successful, will not only help the small farmer (maize and cassava) to stabilize soil on sloping areas, conserve soil moisture and greatly reduce weed competition but also add a considerable quantity of N and organic matter to his soil.

7. USE OF SEWAGE SLUDGE

The use of sewage sludge for food and horticultural crop production has recently gained importance in many developed countries. Concentration of heavy metals in the sludge produced in many industrialized areas is however often high and presents problems in its application on a wide scale. Haan (1976) suggested an average yearly rate of 1-2 tons/ha (dry matter basis) for arable and grassland for sludges of domestic origin containing not more than 2 000 ppm Zn, 500 ppm Cu, Pb and Cr, 50 ppm Ni and 10 ppm Cd and Hg on dry matter basis. Lahann (1976) warned against application of sludges with high Mo content as metabolic disorders in animals often result when Mo-rich herbage is fed to them. Salt-sensitive plants may be affected as a result of increased salinity and chloride levels when sludge and compost are applied (Epstein et al 1976). These workers also found a threefold increase in the CES of soils to which sludge and compost were added. Valdmaa (1969) compared the effect of sewage sludge with farmyard manure and found an average of 10% increases in yields, testing 20 crops.

Presently, hardly any sludge is produced or used in crop production in Africa. However, the potential of its use as an organic fertilizer source is great and research efforts need to be initiated on the subject.

8. FUTURE TRENDS

The present level of technology used on small farms in most countries limits some of the practices of fully utilizing organic residues in crop production. The use of farmyard manure should be encouraged wherever available and efforts be directed towards teaching farmers the need for proper storage and conservation of nutrients in the manure.

Burning of crop residue might have some advantage but this is only temporary. The practice should therefore be discouraged particularly under the "semi-intensive" agricultural system where animal or simple motorized traction is available. Crop residues may be used as mulches which physically and chemically (on decomposition) contribute to maintenance of soil fertility. Incorporation of straw into the soil should be accompanied by the application of N, so as to narrow the C:N ratio.

A well planned cropping system with the inclusion of legumes is one of the most effective methods of improving and maintaining soil fertility. The use of inorganic fertilizers does not only increase crop yield but also enhances greater mass of root production thus indirectly increasing the organic matter content of the soil.

The use of Azolla as a nitrogen fertilizer source or supplement in rice culture. has been successful in Vietnam, China and is recently being adopted in the Philippines. It is desirable to carry out local research into this nitrogen source. Results obtained in Asia with blue green algae for example, may not be applicable as the magnitude of N fixed under Senegal and Mali conditions was found to be a third (6-12 kg N/ha) of that obtained in the Philippines (personal communication). Light intensity is regarded as an important factor.

Crop production in most countries could be reasonably increased if all available sources of fertilizer input - organic and inorganic - as well as improved management practices are properly utilized.

The purpose of the FAO/SIDA Workshop on organic recycling in agriculture in Africa is to examine the question of how best our present knowledge on the subject could be used to assist the farmer to increase his crop production. No doubt, much research and extension remain to be carried out and it is hoped that an effective strategy will emerge from this Workshop.

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Paper 8

THE EFFECT OF VARIOUS TYPES OF MULCHES ON SOIL MOISTURE IN A COFFEE FIELD AT KABETE - KENYA

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(presented by S.O. Keya)

1. INTRODUCTION

Field experiments in Kenya have resulted in the recommendation of mulch as one of the standard cultural practices in coffee management. The value and use of much in various crops is widely accepted. Despite the benefits ascribed to mulches, the practice is not widely adopted due to difficulties of availability and handling of the materials. Problems associated with the supply of vegetative mulches is illustrated by the data of Gillet (1944); an issue of Kenya Coffee (1964) also showed that one hectare of land is required to supply enough napier grass to mulch 2 ha of coffee. Estimates by Sanders (1953) indicate that leaves and stems from 1 ha of banana is needed to mulch 1 ha of coffee.

Mulches help to conserve soil moisture and maintain a uniform moisture supply of the soil through decreased evaporation, increased infiltration, decreased runoff and better weed control (Unger 1975; Rowe-Dutton 1957). Certain mulches aid in breaking the force of water droplets, thus preventing compaction of the soil, they also protect it from exposure to alternate rain and sun which may cause crusting (Rowe-Dutton 1957). On the other hand, penetration of water may also be impeded by certain artificial mulches such as asphalt, paper, aluminum foil and polyethylene sheets. Such mulches may not be effective in increasing soil moisture when used in rainfed agriculture or where overhead irrigation is practised; however, they might have a role where soils are well supplied with groundwater. Whereas artificial mulches offer an alternative possibility, their use has been limited to high value cash crops such as vegetables and pineapples. This study was designed to investigate the effect of polyethylene mulches on soil temperature and moisture, soil nutrients, performance and yield of Arabica coffee at Kabete, Kenya. In this paper only the results related to the influence of mulch on soil moisture and nutrients are reported. The subsequent papers will report the effect of various mulches on soil temperature and coffee yields.

2. MATERIALS AND METHODS

In order to assess the effect of mulch on soil temperature, moisture and growth of coffee, an experiment was conducted at the University of Nairobi Field Station, Kabete. The soil is a deep red, latosol derived from volcanic trachyte commonly known as the Kikuyu red loam. The experiment laid out in a section of the coffee estate was a randomized block design comprising four replicates and five treatments. The mulch treatments included: (1) bare soil (no mulch), (2) napier grass, (3) transparent polyethylene, (4) black polyethylene and (5) white polyethylene. Each treatment covered six coffee bushes separated from the next plot by a guard row of coffee bushes. The width of each mulch was 2.4 metres, leaving 20 cm of unmulched band at the base of the coffee bushes.

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The first sets of mulches were laid out in the middle of April 1976, but some of them deteriorated quickly and had to be reapplied from December 1976 to May 1977. Soil moisture content was examined at 0-15 cm, 60 cm and 120 cm. Flush growth of coffee, assessment of weed growth and chemical soil analysis were recorded at the beginning and end of the experiment.

3. RESULTS

3.1 Soil moisture at 0-15 cm

During the 1976 season, bare soil had less moisture content then mulched soil especially between the 60th and 70th days of the experiment as shown in Fig. 1. For the earlier periods there were no great differences between bare and mulched soil. Table 1 shows that it is only on two sampling dates that bare soil had less moisture than mulched soil.

When comparing grass and polyethylene mulches it can be seen from Fig. 1 that grass mulches registered higher moisture content than the other artificial mulches. Similar results in 1977 season are confirmed in Table 1. The difference between transparent, white and black polyethylene mulch was that, generally, there was a higher soil moisture content under black and white than under transparent polyethylene mulch.

3.2 Soil moisture at 60 cm

In 1976, except on one sampling date, there was no statistically significant difference between grass mulch and bare soil, as shown in Table 2. Similar results were demonstrated in 1977 as shown in Table 3.

Tables 2 and 3 also showed that grass mulch exhibited higher moisture content at 60 cm depth as compared to polyethylene mulches. During the 1976 season, Table 2 shows that transparent polyethylene mulch gave a lower soil moisture content as compared to either black or white polyethylene mulches. On the other hand, in 1977 the transparent mulch did not differ from the other two. In Table 3, it can be seen that where statistical differences were obtained, the white polyethylene mulch gave a higher soil moisture content than the black mulch except on one sampling date.

3.3 Soil moisture content at 120 cm

No statistically significant differences were obtained between bare soil and grass mulch in 1976 as presented in Table 4. However, on three sampling dates in 1977, bare soil recorded lower soil moisture levels than the grass mulch as shown in Table 5. Also, grass mulch gave higher soil moisture content than the polyethylene mulches as confirmed by both Tables 4 and 5. Transparent polyethylene mulch, when compared to black and white polyethylene mulches, generally showed a lower soil moisture content. Lower soil moisture contents prevailed under the transparent mulch than under either the black or white (Table 5).

3.4 Soil moisture between 0-120 cm

The average soil moisture content for the whole profile 0-120 cm depth is shown in Fig. 2 for 1976 and Fig. 3 for 1977. As depicted in Fig. 2, the grass and white polyethylene mulches gave higher soil moisture contents than the bare soil most of the times, while the black mulch indicated a fluctuating soil moisture content. The transparent polyethylene mulch showed a lower soil moisture content than bare soil during most of the experimental period.

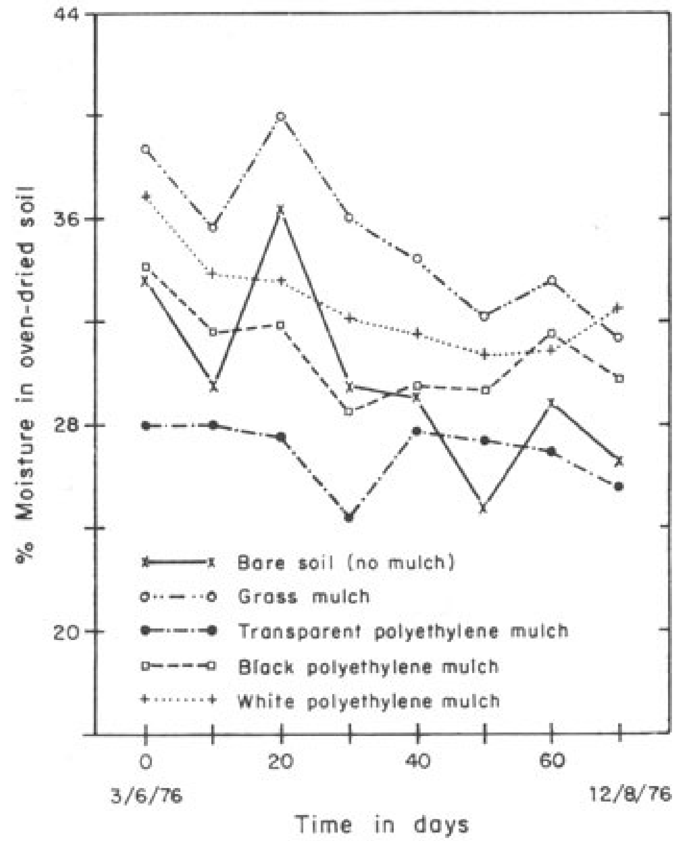


Fig. 1 Average moisture content in oven-dried soil under different types of mulches at 0-15 cm depth (1976)

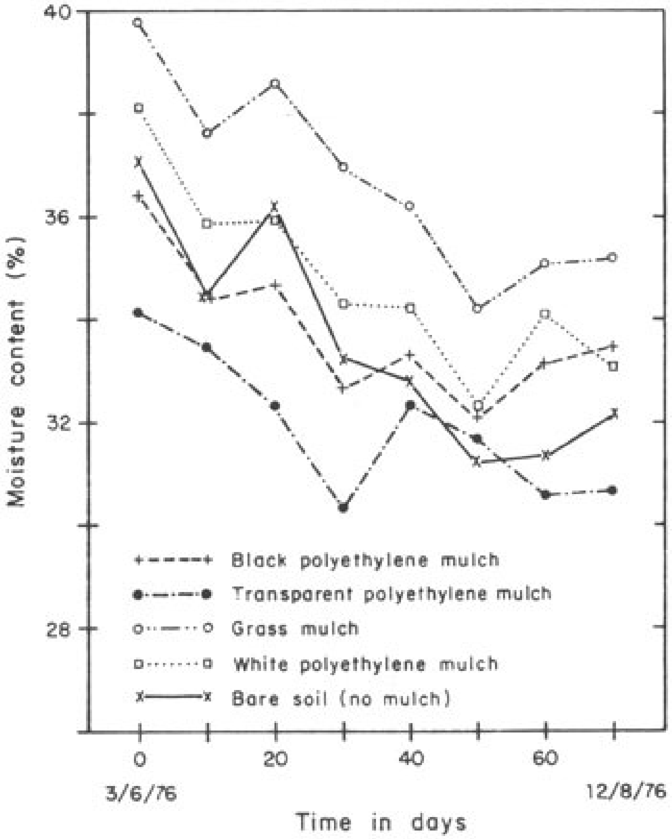


Fig. 2 Average moisture content in oven-dried soil under different types of mulches at 0-120 cm depth (1976)

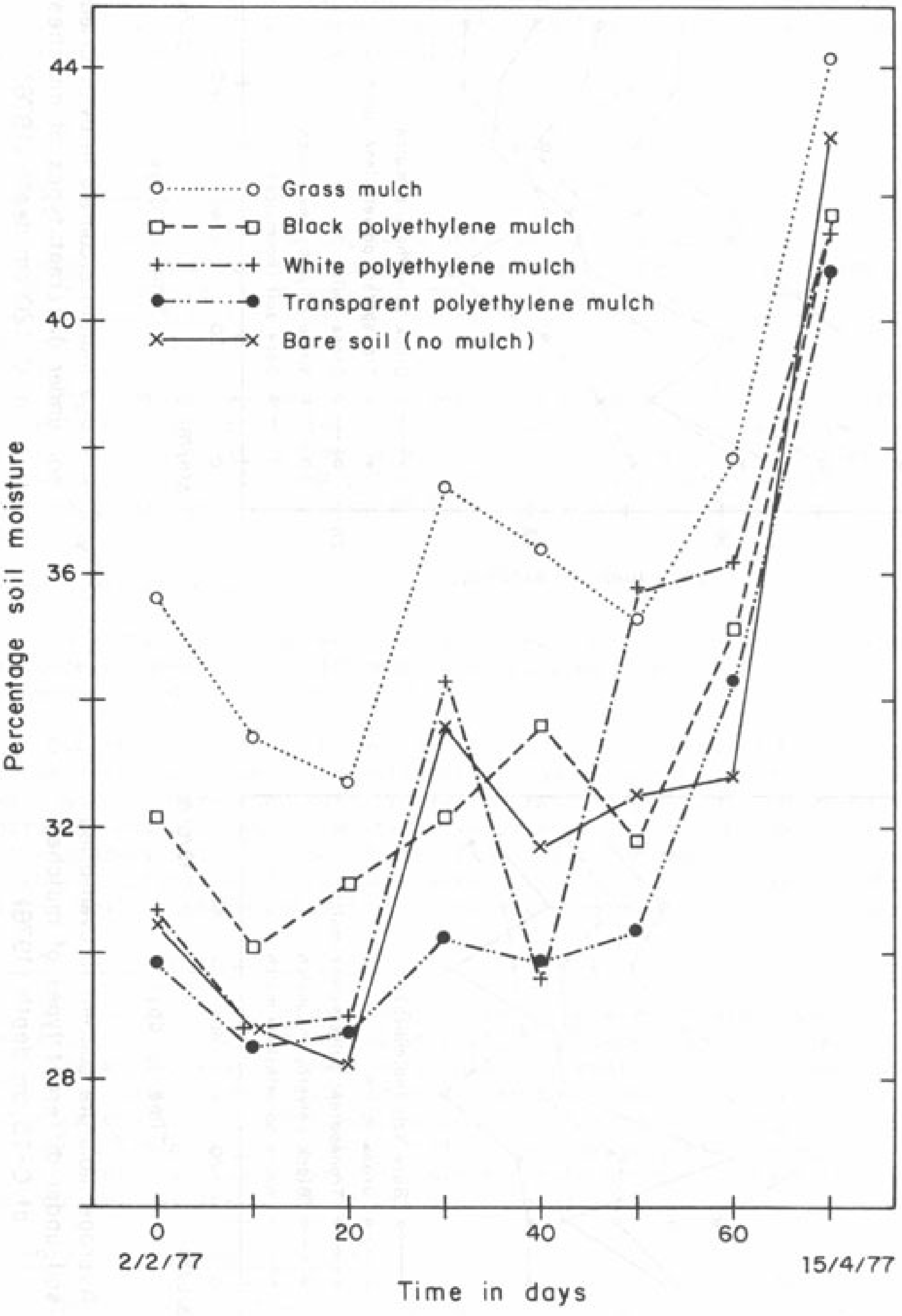


Fig. 3 Average moisture content in oven-dried soil under different types of mulches at 0-120 cm depth (1977)

Table 1

PERCENTAGE MOISTURE IN OVEN-DRIED SOIL AT 0-15 CM DEPTH (1977)

Date	Bare soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
12/1/77	31.79	37.45	32.21	28.60	30.17	3.33	NS	**	NS	NS
2/2/77	28.77	33.72	27.42	32.14	29.43	7.70	NS	*	NS	NS
11/2/77	25.44	32.92	25.94	27.94	26.57	2.39	*	**	NS	NS
22/2/77	28.58	31.23	25.76	30.22	27.70	1.68	*	*	*	NS
4/3/77	33.57	38.27	29.06	34.30	32.85	7.70	NS	*	*	NS
14/3/77	29.90	36.43	28.36	31.48	27.48	4.61	NS	**	NS	NS
24/3/77	36.23	39.22	30.51	30.98	36.71	4.21	NS	**	NS	*
5/4/77	34.81	39.04	35.01	33.60	36.05	5.25	NS	NS	NS	NS
15/4/77	42.96	44.98	38.89	40.65	40.62	3.46	NS	**	NS	NS
5/5/77	40.30	41.94	39.60	35.90	40.12	4.44	NS	NS	NS	NS

Z1 Bare soil vs mulched soil
Z2 Grass mulch vs polyethylene mulches
Z3 Transparent polyethylene vs non-transparent
Z4 Black vs white polyethylene mulches

NS Not significant
* Significant at 5%
** Significant at 1%

Table 2

PERCENTAGE MOISTURE IN OVEN-DRIED SOIL AT 60 CM DEPTH (1976)

Date	Bare soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
13/05/76	35.38	37.46	31.13	31.51	36.12	1.25	NS	**	*	**
3/06/76	38.17	39.24	34.75	35.91	37.90	1.86	NS	*	NS	NS
14/06/76	35.17	37.16	33.97	34.33	35.71	1.74	NS	*	NS	NS
24/06/76	34.70	37.28	32.71	35.02	36.66	2.66	NS	NS	*	NS
2/07/76	33.94	36.52	31.39	33.33	34.14	2.85	NS	*	NS	NS
13/07/76	32.78	36.25	32.62	33.63	35.01	2.77	NS	NS	NS	NS
23/07/76	31.98	34.62	31.66	31.82	32.14	0.73	NS	**	NS	NS
2/08/76	32.31	35.40	31.07	31.80	33.85	1.17	NS	*	NS	NS
12/08/76	31.65	35.26	30.81	32.95	32.95	0.53	*	**	*	NS
21/09/76	29.66	32.85	29.35	31.29	30.73	0.70	NS	**	*	NS
1/10/76	30.22	32.16	30.10	31.79	31.50	0.80	NS	NS	NS	NS
12/10/76	29.02	30.29	29.13	29.58	30.18	0.23	NS	NS	NS	NS

Z1 Bare soil vs mulched soil
Z2 Grass mulch vs polyethylene mulches
Z3 Transparent polyethylene mulch vs non-transparent
Z4 Black vs white polyethylene mulches

NS Not significant
* Significant at 5%
** Significant at 1%

Table 3

PERCENTAGE MOISTURE IN OVEN-DRIED SOIL AT 60 CM DEPTH (1977)

Date	Bare soil	Grass mulch	Transparent polyethylene	Black polyethelene	White polyethylene	SE	Z1	Z2	Z3	Z4
12/1/77	34.28	38.29	30.86	30.30	31.17	1.73	NS	**	NS	NS
2/2/77	31.90	35.22	31.48	30.15	31.10	1.55	NS	**	NS	NS
11/2/77	30.97	33.20	29.17	30.79	29.41	1.18	NS	**	NS	NS
22/2/77	29.32	32.05	29.50	30.98	29.60	0.72	NS	*	NS	NS
4/3/77	33.69	37.04	31.32	30.30	35.63	6.14	NS	*	NS	*
14/3/77	32.26	35.97	30.08	33.91	30.05	1.22	NS	**	NS	**
24/3/77	30.40	31.71	30.00	31.31	37.14	2.61	*	NS	**	**
5/4/77	31.66	38.07	34.54	37.98	36.23	8.49	NS	NS	NS	NS
15/4/77	42.45	43.06	41.38	41.91	41.37	0.50	NS	*	NS	NS
5/5/77	41.24	41.49	40.07	38.84	41.41	0.61	NS	NS	NS	*

Z1 Bare soil vs mulched soil

Z2 Grass mulch vs polyethylene mulches

Z3 Transparent polyethylene mulch vs non transparent

Z4 Black vs white polyethelene mulches

NS Not significant

* Significant at 5%

** Significant at 1%

Table 4

PERCENTAGE MOISTURE IN OVEN-DRIED SOIL AT 120 CM DEPTH (1976)

Date	Bare soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
13/05/76	35.56	37.29	34.51	32.86	34.31	1.50	NS	**	NS	NS
3/06/76	38.96	41.55	39.57	39.21	39.83	2.40	NS	NS	NS	NS
14/06/76	37.20	39.41	37.94	37.20	38.23	1.34	NS	NS	NS	NS
24/06/76	37.34	38.60	35.68	37.18	38.60	1.05	NS	NS	*	NS
2/07/76	36.24	37.96	35.48	36.37	36.62	2.00	NS	NS	NS	NS
13/07/76	36.20	38.31	36.22	37.05	36.65	0.97	NS	NS	NS	NS
23/07/76	33.94	35.93	35.98	35.40	34.98	0.83	*	NS	NS	NS
2/08/76	36.26	38.55	35.80	36.14	36.26	1.27	NS	*	NS	NS
12/08/76	36.12	37.63	34.37	36.05	35.38	0.71	NS	NS	*	NS
21/09/76	32.64	35.73	31.95	34.45	34.27	0.95	NS	*	*	NS
1/10/76	33.18	34.92	34.00	35.35	35.36	0.99	NS	NS	NS	NS
12/10/76	32.49	33.24	33.20	32.28	34.29	0.97	NS	NS	NS	NS

Z1 Bare soil vs mulched soil

Z2 Grass mulch vs polyethylene mulches

Z3 Transparent polyethylene mulch vs non-transparent

Z4 Black vs white polyethylene mulches

NS Not significant

* Significant at 5%

** Significant at 1%

Table 5

PERCENTAGE MOISTURE IN OVEN-DRIED SOIL AT 120 CM DEPTH (1977)

Date	Bare soil	Grass mulch	Transparent polyethylene	Black polyethylene	White polyethylene	SE	Z1	Z2	Z3	Z4
12/1/77	31.87	40.26	31.42	33.52	32.02	1.84	*	**	NS	NS
2/2/77	31.30	38.55	32.11	34.34	32.23	1.24	*	*	NS	NS
11/2/77	31.18	34.23	31.75	31.89	30.87	0.83	NS	**	NS	NS
22/2/77	29.90	34.80	31.10	31.97	29.95	0.60	*	**	NS	*
4/3/77	33.86	36.63	30.88	32.53	34.34	2.53	NS	**	*	NS
14/3/77	33.37	36.82	31.33	36.04	31.84	0.87	NS	**	**	**
24/3/77	30.83	35.37	30.72	33.13	33.00	1.71	NS	*	NS	NS
5/4/77	31.91	36.70	33.30	34.05	36.21	4.97	NS	NS	NS	NS
15/4/77	43.73	44.69	42.18	43.00	42.63	0.18	NS	**	NS	NS
5/5/77	41.86	42.57	42.79	42.53	44.54	1.87	NS	NS	NS	NS

Z1 Bare soil vs mulched soil

Z2 Grass mulch vs polyethylene mulches

Z3 Transparent polyethylene mulch vs non-transparent

Z4 Black vs white polyethylene mulches

NS Not significant

* Significant at 5%

** Significant at 1%

Figure 3 illustrates that grass mulch recorded the highest soil moisture content among all the treatments. The black and white polyethylene mulches gave higher soil moisture contents than the bare soil, while the transparent polyethylene mulch showed a lower soil moisture content than the bare soil.

Monthly average rainfall for 1976 and 1977 and monthly air temperatures at Kabete are shown on Figs. 4 and 5. These figures might help explain the precipitation and potential evapotranspiration of the experimental site.

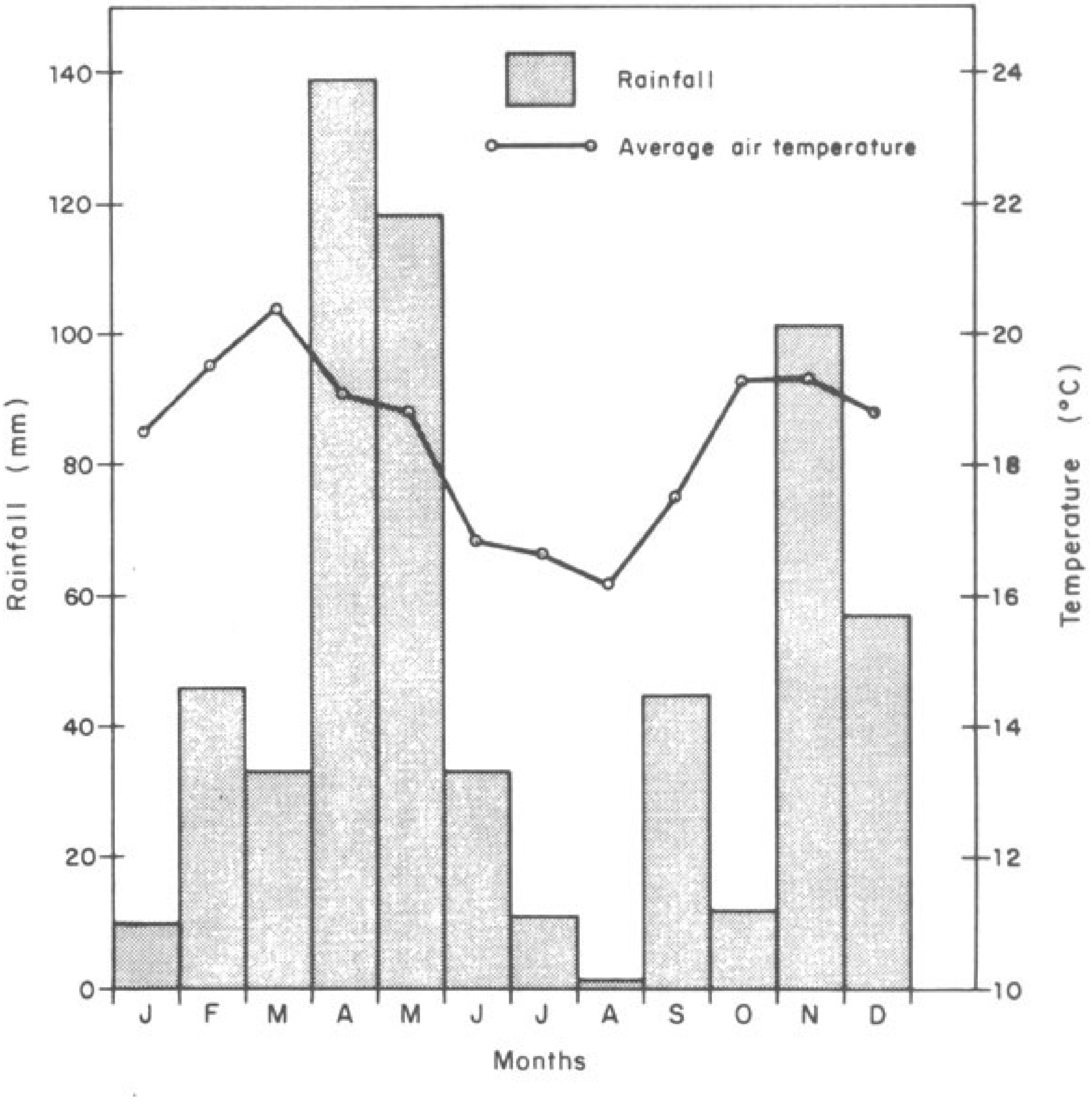


Fig. 4 Rainfall at Kabete during the year 1976

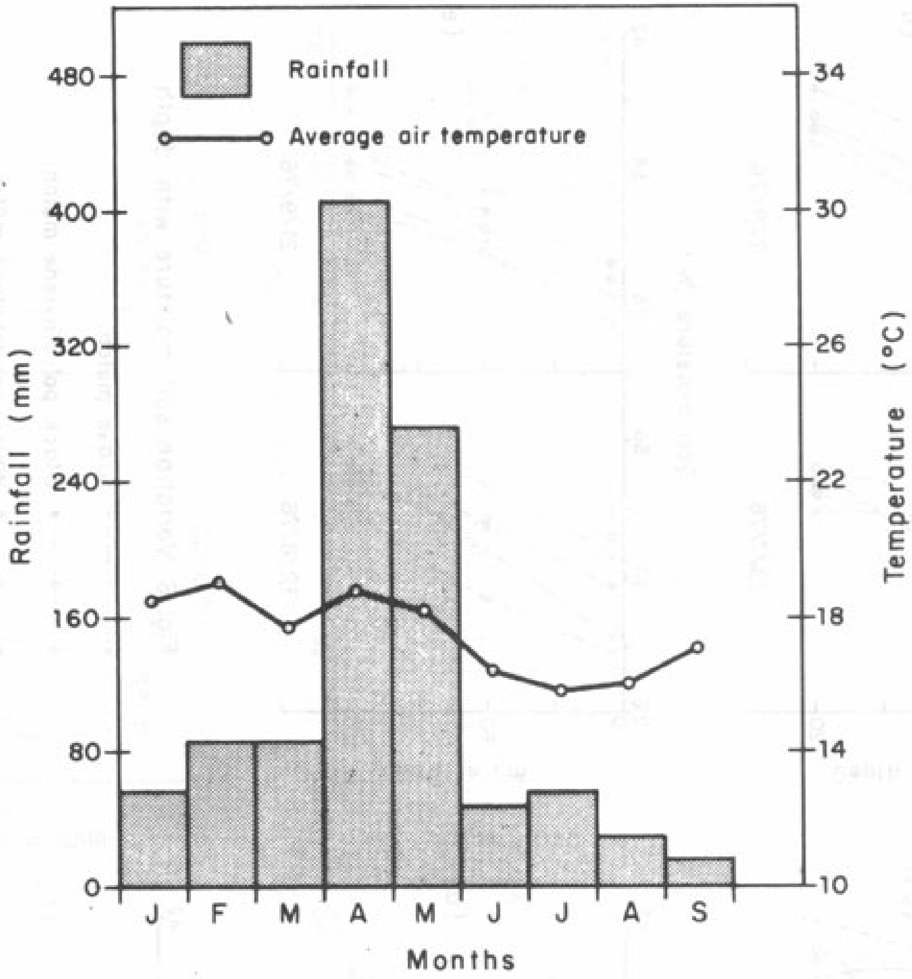


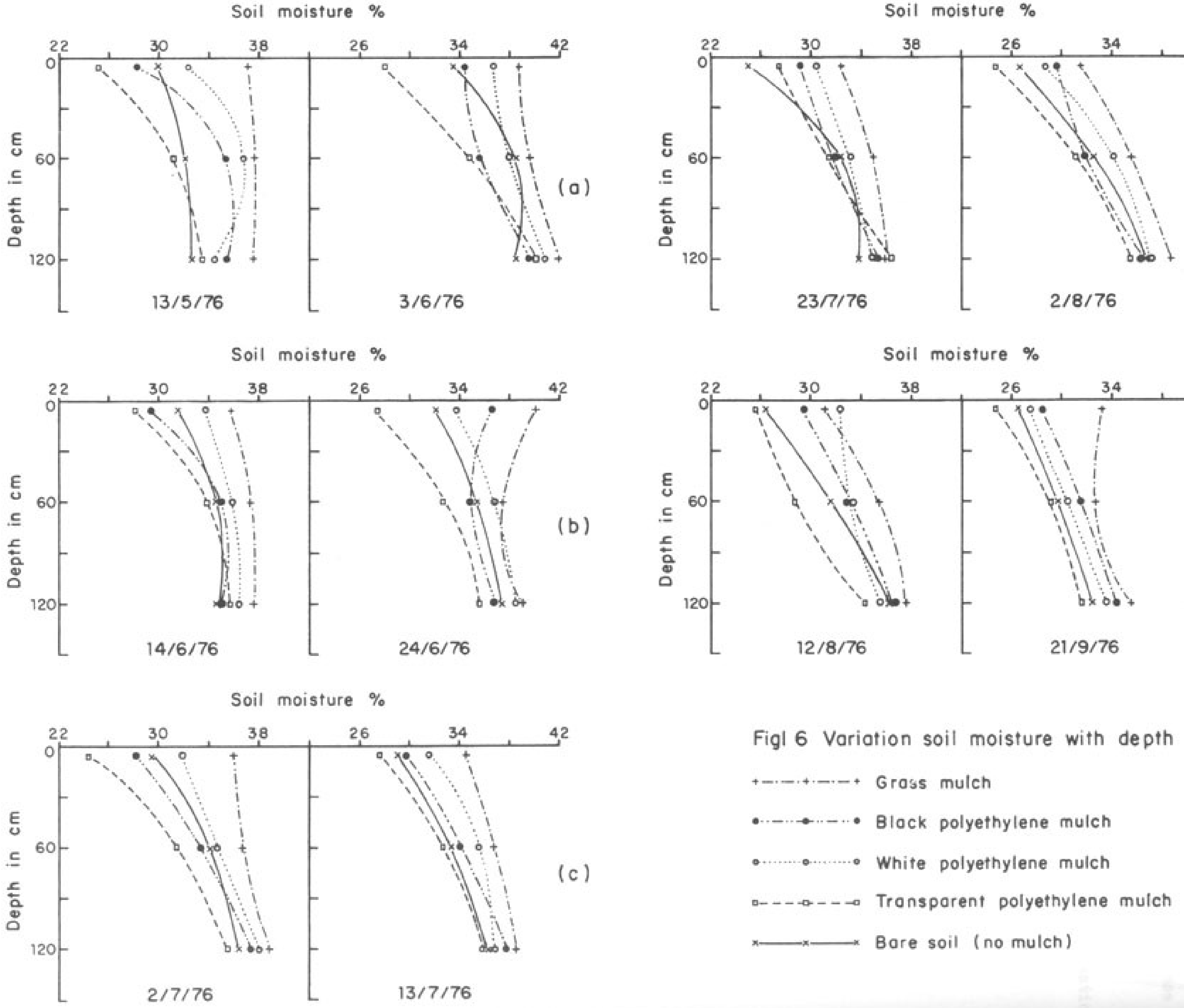
Fig. 5 Rainfall at Kabete part of 1977

3.5 Variation of Soil Moisture with Depth

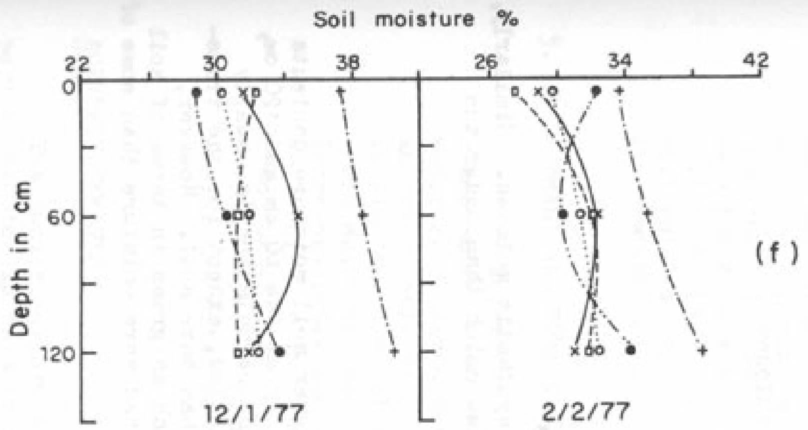
Variations of soil moisture with depth during 1976 and 1977 are shown on Figs. 6 (a) - (j). Soil moisture content increased from the surface (0–15 cm) to the lower horizons (120 cm). The lower soil horizons thus conserved more moisture than the surface layers. Considering the various mulches, it was found that grass mulch gave the highest soil moisture content for the 0–120 cm depth; the white polyethylene was next to the grass, followed by black polyethylene. These three mulches conserved more moisture than bare soil. It was observed that transparent mulch gave a lower soil moisture than bare soil, especially at 0–15 cm depth. Differences between the various mulches tended to narrow down at the 120 cm depth.

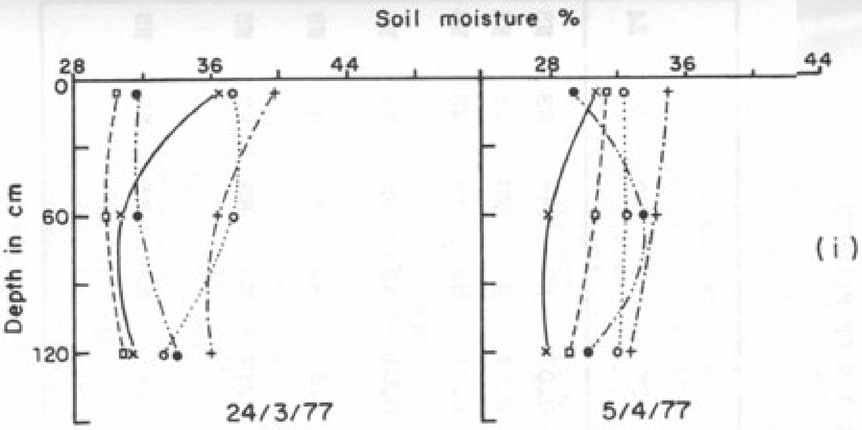
3.6 Influence of Mulches on Soil Chemical Properties

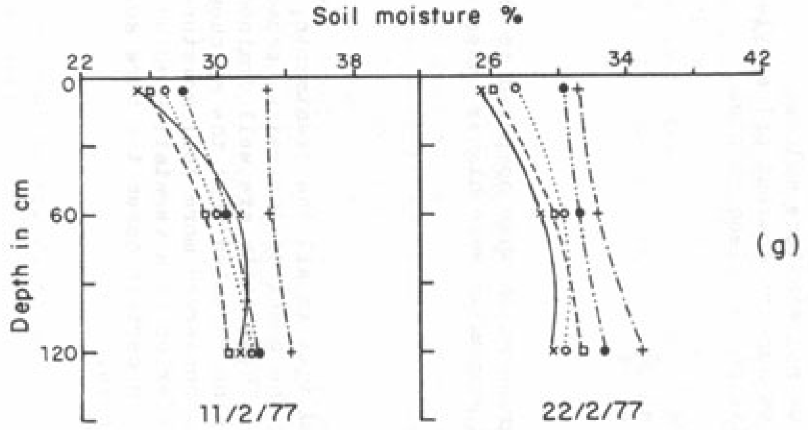
Analysis of soil chemical properties performed on the 0–15 cm bulked samples are shown on Table 6. It can be seen that grass mulch increased the percentage carbon in the soil more than the polyethylene mulches. The cation exchange capacity

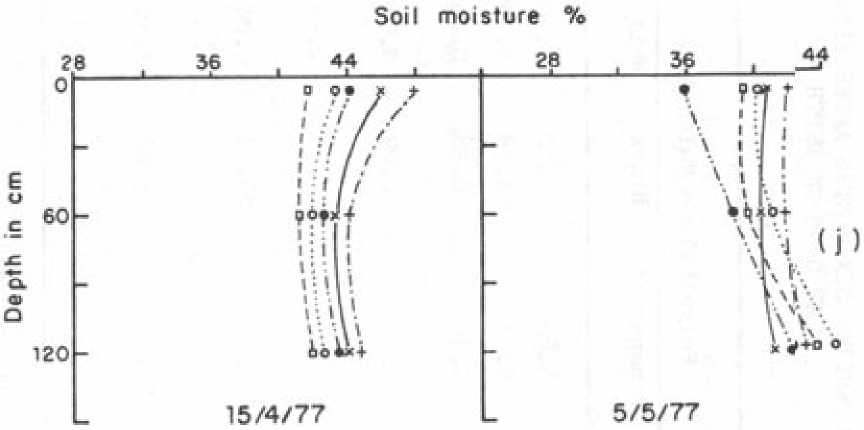


Figl 6 Variation soil moisture with depth


Soil moisture %
22
30
38
26
34
42
Depth in cm
0
60
120
12/1/77
2/2/77
(f)


Soil moisture %
28
36
44
28
36
44
Depth in cm
0
60
120
24/3/77
5/4/77
(i)


Soil moisture %
22
30
38
26
34
42
Depth in cm
0
60
120
11/2/77
22/2/77
(g)


Soil moisture %
28
36
44
28
36
44
Depth in cm
0
60
120
15/4/77
5/5/77
(j)

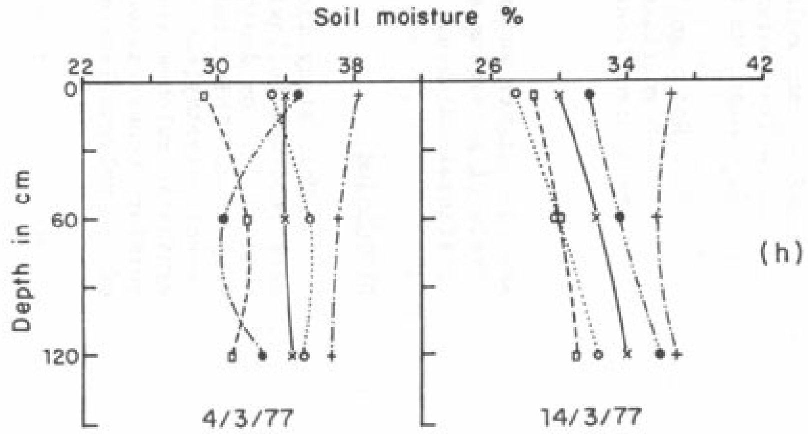

Soil moisture %
22
30
38
26
34
42
Depth in cm
0
60
120
4/3/77
14/3/77
(h)

Table 6 SOIL CHEMICAL PROPERTIES SIX MONTHS AFTER APPLICATION OF MULCHES AT 0-15 CM DEPTH

Analysis	Bare soil	Grass mulch	Polyethylene Mulches			SE	Z1	Z2	Z3	Z4
			Transparent	Black	White					
% Carbon	3.80	4.40	3.60	3.70	3.60	0.07	NS	**	NS	NS
% Nitrogen	0.45	0.41	0.34	0.38	0.32	0.01	NS	NS	NS	NS
Potassium meq %	0.24	0.46	0.26	0.28	0.28	0.01	NS	**	NS	NS
Sodium meq %	0.09	0.09	0.11	0.09	0.09	0.01	NS	NS	NS	NS
Magnesium meq %	3.88	4.79	3.62	3.75	2.96	0.43	NS	*	NS	NS
Calcium meq %	22.25	20.75	23.09	20.69	20.04	2.19	NS	NS	NS	NS
Cation Exchange Capacity (CEC)	24.40	26.70	24.30	25.00	24.10	0.47	NS	**	NS	NS

Z1 = Bare soil vs mulched soil
Z2 = Grass mulch vs polyethylene mulches
Z3 = Transparent vs non-transparent polyethylene mulches
Z4 = Black vs white polyethylene mulches

NS = Not significant
* = Significant at 5%
** = Significant at 1%

was also higher under grass mulch when compared to the synthetic mulches. Similarly, levels of potassium and magnesium were higher under grass mulch than under the artificial mulches.

4. DISCUSSION

This study showed that in all the treatments, higher soil moisture contents were recorded following the onset of the rains, especially at the 60 cm and 120 cm, than at 0-15 cm depths. These soils are well drained and percolation is usually very good. This study also revealed that the mulches tested, except for the transparent polyethylene one, conserved more soil moisture than bare soil. However, synthetic mulches are inferior to a vegetative mulch such as grass in terms of soil moisture conservation. In certain cases the bare soil had more moisture than some of of the polyethylene mulches.

The findings in this investigation are in agreement with those of Pereira and Jones (1954); Gilbert (1945) and Foster (1962) who found that vegetative mulches do allow for increased soil moisture content as a result of increased infiltration, control of weeds, reduced runoff and evaporation. Increased soil moisture under black and white polyethylene mulches can therefore be attributed to decreased evaporation, weed control and reduced runoff.

The transparent polyethylene mulch consistently exhibited lower soil moisture. This might be explained by the fact that soil temperatures under this treatment were the highest. In addition, transparent polyethylene mulch permitted weed growth resulting in a possible enhanced evapotranspiration. The polyethylene mulches are generally impermeable to rain water, thereby hindering uniform and direct penetration of water into the soil. It was observed that rain water tends to collect at localized spots and some of this water might be lost through direct evaporation. Rowe-Dutton (1957) has reported that materials that impede penetration of rain water into the soil, could be effective in increasing soil moisture only if used on soils well supplied with groundwater rather than on those dependent on rain or overhead irrigation.

That grass mulch increased the organic matter status of the soil is often reported and was also confirmed in this study. Maintenance of organic matter in the soil is an important aspect of soil fertility. Apart from improving infiltration, reducing runoff, conserving soil moisture and releasing plant nutrients on its decomposition, grass mulch emerged superior to the synthetic mulches.

The high temperatures and low moisture content of tropical soils during the dry season are often followed by a high moisture recharge at the beginning of the rainy season. This cycle of wet and dry periods results in the accumulation of nitrates during the dry season and their flushing with the onset of rain which has been described by Birch (1960). He showed that the intensity of drying, the length of the dry period and the drying temperature are all important in determining the magnitude of organic matter decomposition on remoistening the soil. While the benefits of the nitrogen flush are realized, the fluctuating moisture regime of the soil might have implications in the rundown of soil fertility. Stabilization of soil moisture by mulches could therefore be one of the ways of reducing the nitrogen flush which may be undesirable under certain farming systems.

5. SUMMARY AND CONCLUSION

Studies conducted during a one year period with coffee showed that vegetative grass mulch is superior to artificial polyethylene mulches with respect to soil moisture conservation. In general, mulching increased the soil moisture content and since moisture is often a limiting factor in plant growth, it is suggested that in bimodal rainfall areas the practice of mulching coffee be continued. In addition, grass mulch increased soil organic matter, CEC, magnesium and potassium. However, increased potassium might result in induced magnesium deficiency. Regulation of soil moisture is considered desirable not only for the attainment of high yields but also for the conservation of soil organic matter. In areas with wet and dry seasons, mulches might help in the slow release of mineral soil nitrogen consequently minimizing the nitrogen flush.

ACKNOWLEDGEMENTS

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Paper 9

THE EFFECT OF EDAPHIC FACTORS ON N_2 FIXATION WITH SPECIAL EMPHASIS ON ORGANIC MATTER IN SOILS

Y.R. Dommergues [1]

1. INTRODUCTION

Although the state of our knowledge of the influence of edaphic factors on legume-Rhizobium symbiosis is relatively well advanced, many questions remain unanswered about the role of soil organic matter (cf. Shina 1977) and we have very little information about the influence of edaphic factors on rhizospheric and asymbiotic N_2 fixation.

In this paper, three categories of processes will be considered:

i. symbiotic N_2 fixation, restricted to the case of legume-Rhizobium symbiosis and to that of the Azolla-Anabaena symbiosis;

ii. rhizospheric N_2 fixation, i.e. N_2 fixation by diazotrophs associated with the root system (either living, dying or dead roots); and

iii. asymbiotic N_2 fixation, i.e. N_2 fixation by free-living diazotrophs, either bacteria or blue-green algae.

The aim of this review is to draw attention to aspects of the ecology of N_2 fixation hitherto overlooked and to suggest steps necessary to increase this beneficial microbial activity through better soil management. Although we are particularly concerned here with edaphic factors, one should keep in mind the fact that N_2 fixation by a given system or organism also depends upon climatic conditions, especially light.

2. EDAPHIC FACTORS OTHER THAN ORGANIC MATTER

2.1 Edaphic Factors Affecting the Rhizobium-legume Symbiosis

Since the influence of edaphic factors other than organic matter on the Rhizobium-legume symbiosis has been recently reviewed by Gibson (1977), we shall give here only a brief account of our present knowledge of this problem, restricting the discussion mainly to the case of tropical legumes.

2.1.1 Physical factors

Soil temperature is known to have marked effects on nodulation and nitrogen fixation. In tropical soils nodulation is adversely affected by the high temperatures often encountered in semi-arid or arid soils. Thus, nitrogen fixation by chick pea is inhibited when temperatures rise to 33°C during the day (Dart *et al* 1975).

Some attention has been given recently to the influence of moisture stresses on Rhizobium-legume symbiosis: deficiency and excess are both detrimental. Nodulation does not occur when the soil is too dry (Beadle 1964; Diatloff 1968). Such was the case for groundnuts in central Senegal 1977. Nodulation was delayed by drought up to the 50th day after sowing so

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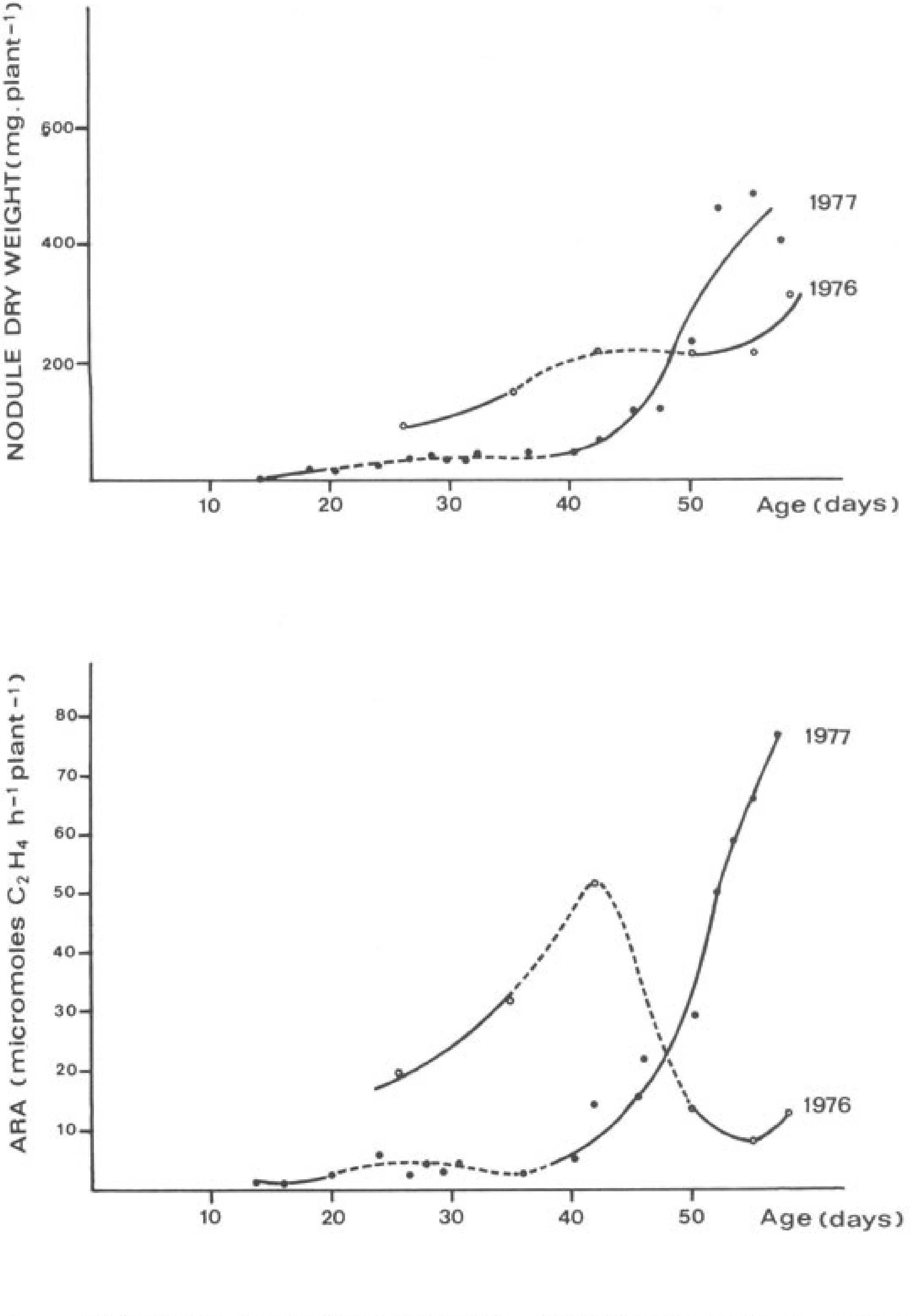

Fig. 1 Age: nodule dry weight and age: N_2 (C_2H_2) fixing activity of field grown groundnuts over the first part of two growing seasons. For each year drought spells are indicated by interrupted lines. The 1976 drought lasted from the 35th day up to the 50th day; the 1977 drought lasted from the 20th day up to the 38th day. (Ducerf, unpublished).

that N_2 fixation (measured by the ARA, acetylene reducing activity) only started after that date (Fig. 1). Even when plants are well nodulated, N_2 fixation can be severely depressed by a moisture stress occurring after most nodules have been formed (Sprent 1972). This situation occurred in the case of groundnuts in central Senegal in 1976: a drought that occurred in the middle of the growth cycle drastically reduced measured ARA (Fig. 1). Recent soybean studies have shown that N_2 fixation appeared to "be affected only slightly by the moisture content of soil around the nodules, if plants received adequate moisture from below the nodule zone" (Hume et al 1976). Soil moisture deficits are often associated with high soil temperatures, so that it is difficult to infer the respective role of moisture deficit and temperature excess from field studies. Such conditions may limit the areas and seasons in which legumes can be grown (Dart 1976). Waterlogging, especially when associated with poor soil structure, is responsible for low oxygen levels in soils. The general topic of the effect of the gaseous environment on nodulation and symbiotic function was discussed in detail by Pate (1975), Minchin and Pate (1975)and Criswell et al (1977). Here it will be sufficient to recall that waterlogging drastically reduces nodulation and N_2 fixation (e.g. Diatloff 1968). The relatively high O_2 requirements of the nodules may explain the following conclusions of experiments performed in Israel on the inoculation of irrigated groundnuts during the hot and dry season; "the placement of the inoculum at a depth of 12 cm resulted in poorer nodulation than at a depth of 3-4 cm, despite the higher soil moisture at the greater depth" (Shimshi et al 1967).

2.1.2 Chemical factors

Much is known about the nutrients required for the legume, the Rhizobium and for the legume-Rhizobium association itself. These aspects and the effect of soil acidity have been reviewed in detail elsewhere, (Quispel 1974; Hardy and Gibson 1977). We shall only recall here that nodulation is mainly affected by calcium, boron, acidity and, to a lesser extent, phosphorus and sulphur. The functioning of the symbiosis is mostly dependent upon molybdenum, sulphur, calcium and boron (Dart 1976). Soil acidity, which is prevalent in tropical situations, is generally associated with low Ca, P and Mo contents and high Al and eventually Mn contents. Though tropical legumes in their nodulation and nitrogen fixation are generally more tolerant to low soil pH than temperate legumes, liming is often useful, together with application of Mo if this element is deficient (e.g. Day and Franco 1976). Groundnut in its nodulation and nitrogen fixation is relatively tolerant to acid pH and high aluminum levels (Dart 1976). Excessive pH (> 8.0), resulting from irrigation or ashes originating from burning crop residues, markedly limits groundnut nodulation (Ganry 1977; Dreyfus 1977, personal communications). Since legumes require relatively large amounts of phosphorus, except when they are associated with vesicular-arbuscular mycorrhizae (Mosse et al 1976), application of P fertilizers is nearly always recommended in tropical conditions.

Soluble combined nitrogen is known to decrease nodulation of legumes (cf. Dart's review, 1974). However, nitrate induced inhibition is not so well established (Gibson 1977). On the other hand, N_2 fixation is stimulated by small amounts of combined N (starter nitrogen) applied before the nodules are formed, i.e. during a phase of nitrogen hunger. Later the effect of combined nitrogen is obviously depressive. The relationship between total plant nitrogen during a growing season has been diagrammed by Gibson (1977) (Fig. 2). The use of fertilizers compatible with N fixation has been suggested by Hardy et al (1973) as a means of overcoming this inhibiting effect of conventional nitrogen fertilizers (Table 1).

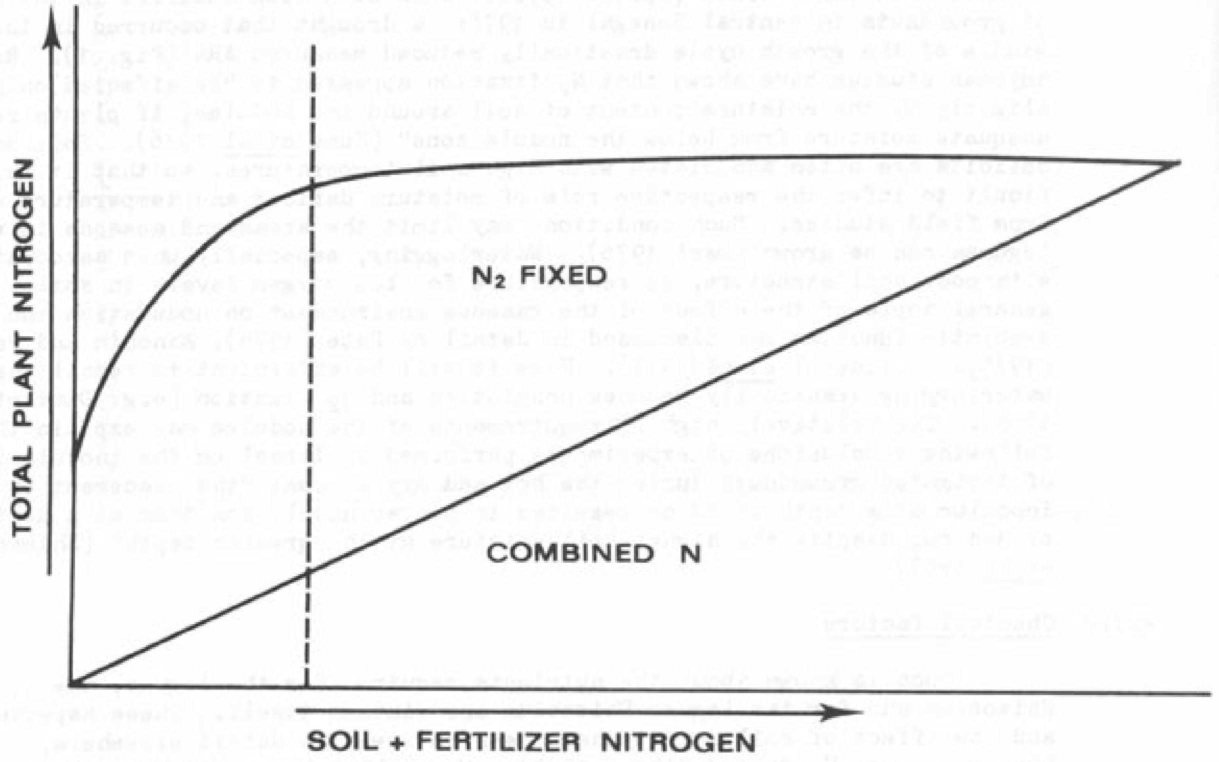

Fig. 2 Diagramatic representation of the effects of combined nitrogen (soil plus fertilizer) on the nitrogen assimilation by legumes over a growing season (Gibson 1977).

Table 1 INCORPORATION INTO THE SOIL OF SOYBEAN MEAL, UREA AND AMMONIUM FERTILIZER AND ITS EFFECT ON N_2 FIXATION AND YIELD OF FIELD-GROWN SOYBEAN (Hardy *et al* 1973)

Application	N2 (C_2H_2 fixation	Yield
Soybean meal	112	123
Urea	48	109
NH_4^+ fertilizer	51	104

Data expressed as a percentage of control.

2.1.3 Biological factors

Among the edaphic factors, biological factors are sometimes overlooked. Such an omission may obscure the interpretation of environmental studies. Biological factors include non-pathogenic micro-organisms (e.g. micorrhizae, saprophitic bacteria) or pathogenic organisms (viruses, insects, nematodes) that affect nodulation and N_2 fixation.

The adverse effect of antagonistic micro-organisms was often reported to reduce nodulation (cf. Dart 1974, for reference list; Kumara Rao et al 1974). Practical means of overcoming this antagonism are urgently needed in some semi-arid soils. Competition between Rhizobium strains is another difficult problem, which has hitherto had no practical solution. Nematode infection has been reported to inhibit nodulation by some unknown process; nematodes can also invade the nodule (see Gibson 1977, for reference list; Germani and Dhery 1973; Germani and Gautreau 1976). Application of nematicides restores nodulation and consequently N_2 fixation. However, unfavourable after-effects of nematicides on N_2 fixation have been reported, resulting from a disequilibrium of the nematode populations (Germani 1977, personal communication). Such experimental data suggest that more elaborate methods of pest control are urgently needed in order to maintain the legume potential of N_2 fixation. Recently, attention has been given to the effect of endomycorrhizae on the legume-Rhizobium symbiosis: endomycorrhizae do not only substantially increase P uptake by the plant but also lower the host root's resistance to water transport, probably by improving the nutrient uptake (Safir et al 1972). Endomycorrhizae improve both nodulation and N_2 fixation (Mosse et al 1976; Dart 1976). Suitable mycorrhizal inoculation together with application of some form of organic matter and phosphorus fertilizer should allow the extension of legume crops in poor tropical soils. However, more research is needed in order to produce endomycorrhizal inoculants on a proper scale.

Development of legume crops is often adversely affected by different pathogens and insects which impede nodule development and symbiotic N_2 fixation. Such limiting factors should not be overlooked, especially in stressed conditions.

2.2 Edaphic Factors Affecting Rhizospheric and Asymbiotic N_2 Fixation

Relatively little attention has been given to the effect of edaphic factors on these processes. But with growing interest in rhizospheric N_2 fixation, investigations are currently underway to elucidate the role of the main limiting edaphic factors.

2.2.1 Physical factors

Contrary to symbiotic N_2 fixation, rhizospheric and asymbiotic fixation are markedly promoted by waterlogging (e.g. Dommergues et al 1972), which explains why high rates of rhizospheric N_2 fixation are associated with plants in waterlogged habitats: rice (e.g. Balandreau et al 1976; Yoshida 1971, 1972), Juncus (Tjepkema and Evans 1976), marine grasses such as Thalassia (Patriquin and Knowles 1972), Avicennia and Rhizophora sp. (Silver et al 1976). These results are perfectly consistent with the well known sensitivity of the nitrogenase system and pure culture of diazotrophs, even aerobic ones (see Knowles 1976, for reference list). Conversely, moisture deficits severely depress rhizospheric N_2 fixation. As far as moisture is concerned, the behaviour of N_2 fixing algae is parallel to that of diazotrophs associated with plant roots.

Temperature is also a key factor which acts directly upon the diazotroph or through the plant (rhizospheric diazotrophs); low temperatures were shown to limit rhizospheric fixation (Balandreau et al 1977).

2.2.2 Chemical factors

Soluble combined nitrogen inhibits rhizospheric N_2 fixation. However, preliminary data (Rinaudo and Ganry, personal communications) indicate that starter doses of nitrogen would be beneficial. On the other hand, field experiments set up by Smith et al (1976) suggest that application of medium rates of nitrogen fertilizer would stimulate rhizospheric N_2 fixation. In a fertility trial with lowland rice, nitrogen dressing (140 N ha^{-1}) inhibited nitrogen fixation only temporarily. Since rice plants rapidly absorb ammonium nitrogen, nitrogen repression is restricted to the first stages of growth (Trolldenier 1977). The critical threshold apparently varies widely with the soil type and the plant.

2.2.3 Biological factors

Diem et al (1977) indicated that actinomycetes may account for the limited development of a Beijerinckia strain in an alluvial paddy soil of Camargue, suggesting that antagonists may eliminate diazotrophs from certain habitats.

3. INFLUENCE OF ORGANIC MATTER ON N_2 FIXATION

3.1 Influence of Organic Matter on Symbiotic N_2 Fixation

The overall effect of organic matter on N_2 fixation by legumes was reported to be generally, but not always, beneficial. Most examples given here are related to the incorporation of crop residues, animal manure, especially farm yard manure (FYM), compost and some other compounds. From pot experiments, wheat straw incorporation (3 and 6 t ha^{-1}) was shown to increase the yield of soybean from 0.871 (control) to 0.925 and 1.022 g, and the total protein content of seeds from 273 mg (control) to 301 and 358 mg respectively (Shiwshankar et al 1976). This effect of wheat straw incorporation was attributed to CO_2 enrichment of the lower atmosphere, which is known to improve N_2 fixation (Havelka and Hardey 1976). Addition of soybean meal at 135 kg N ha^{-1}, increased the yield of field grown soybean by 23% and N_2 (C_2H_2) fixation by 12%, suggesting that soybean meal acted as a source of nitrogen compatible with N_2 fixation, whereas urea or NH_4^+ application inhibited nitrogen fixation (Table 1).

Mulder and Van Veen (1960) reported that extracts of stable manure "not only promoted multiplication of Rhizobium trifolii infection of the roots but also the growth of the nodules". This stimulative effect was the same as that observed with yeast extract and sterilized Rhizobium cells. No explanation of the observed effect was proposed. Stimulation of soybean nodulation by organic matter and manure was also reported by Johnson and Hume (1972).

Saint-Macary (personal communication, 1977) studied the effect of the addition of different forms of organic matter, compared with urea and urea-formaldehyde, on nodulation and N_2 fixation in soybean plants (cv. Jupiter) grown in the open in pots using a sandy Senegalese soil (Dior). Additions expressed in terms of nitrogen were made at the rate of 30 and 60 kg N ha^{-1}. Table 2 indicates that application of animal manure (60 kg N ha^{-1}) did not affect nodulation and increased N_2 fixation measured by Acetylene Reducing Activity (ARA) slightly, though not significantly, suggesting that the animal manure used in his experiment behaved like a compatible fertilizer. Contrary to wheat straw, pearl millet straw appeared to inhibit nodulation and ARA.

Table 2 EFFECT OF THE ADDITION OF DIFFERENT FORMS OF ORGANIC MATTER, COMPARED WITH UREA AND UREA FORMALDHYDE ON NODULATION AND NITROGEN FIXATION BY 60-DAY OLD SOYBEANS

(Saint-Macary, personal communication, 1977)

Inoculation with proper Rhizobium	Application 1/	Nodule fresh weight (g plant $^{-1}$)	C_2H_2 reduced (nanomoles plant $^{-1}$h $^{-1}$)
0	No application	0.21	1 550
+	No application	1.73	12 960
+	Pearl millet straw	0.80	4 290
+	Compost	1.09	11 930
+	Animal manure	1.58	13 930
+	Urea	1.08	9 380
+	Urea formaldehyde	1.41	12 230

1/ Application rates were claculated on the basis of an addition of 60 kg N ha $^{-1}$. Figures are means of 5 replicates

Table 3 AFTER-EFFECTS OF DIFFERENT TYPES OF ORGANIC MATTER ON N_2 FIXATION IN GROUNDNUTS EXPRESSED IN mg OF N_2 FIXED PER PLANT

(Ganry, Guiraud and Dommergues, unpublished)

Treatments	Estimation of N_2 fixation by two methods	
	^{15}N	Difference
Control	101	97
Incorporation of Pearl millet straw	111	101
Incorporation of compost	142	158
Incorporation of FYM	136	146

This discrepancy cannot be attributed to the rate of application of straw (9-18 g/pot of 3 kg in Saint-Macary's experiment) but possibly could result from the relatively high concentration of phenolic compounds which are present in pearl millet straw (Ganry et al 1978). Application of animal manure to field grown groundnuts in Senegal was shown to increase ARA by ca. 50% (Ganry and Wey, personal communication).

After-effects of different types of organic matter on N_2 fixation in pot-grown groundnuts were estimated by Ganry et al using two methods: (1) calculation of N_2 fixation from dilution of ^{15}N derived from the soil in the N_2 fixing plant (Legg and Sloger 1977); (2) determining the difference between the total N content in groundnuts and total N content in a non-N_2 fixing plant taking up the same amount of soil nitrogen (rice). Compost and FYM markedly favoured N_2 fixation, which was increased by 30 - 50%. On the other hand, pearl millet straw had no effect (Table 3). The latter result seems to be inconsistent with results reported in Table 2. The discrepancy can be attributed to the fact that in one case (Table 2) straw was incorporated a short time before the legume was sown and in the other case (Table 3) straw had been incorporated the previous year.

Preliminary observations suggest that green manure could significantly depress N_2 fixation in groundnuts (Ganry, personal communication). A few experiments were carried out, using somewhat purified humic compounds such as humic acid or fulvic acid. Favourable effects on the Trifolium-Rhizobium symbiosis were reported by Bhardwaj and Gaur (1968) and Myskow (1970). Dart et al (1973) showed that soil organic matter favourably affected the growth and nodulation of two legumes Vigna mungo and V. radiata. Neither species grew well in nitrogen free sand: grit mixture, but adding 10% by volume of Kettering loam, improved the growth and nodulation. When added loam had been previously ignited at 450°C for 4 h to remove soil organic matter, plant growth was poor and plants eventually died.

3.2 Influence of Organic Matter on Rhizospheric N_2 Fixation

Comparisons of rhizospheric N_2 fixation carried out with the same rice cultivar in different soil types have shown that this biological process depends critically on the soil type. Thus, Rinaudo et al (1971) reported large variations in the Acetylene Reducing Activity (ARA) of the rhizosphere of IR8 rice seedlings grown in three different soils from the Ivory Coast (Table 4). Obviously, such variations are not related to the organic matter content of the soil. Moreover, in contrast with the established fact that combined nitrogen inhibits the activity of diazotrophs, the highest ARA occurred in the soil with the highest total nitrogen content. This result suggests that some forms of organic soil nitrogen could probably be compatible with N_2 fixation.

Table 4 ACETYLENE REDUCING ACTIVITY (ARA) OF THE RHIZOSPHERE OF 20-DAY OLD IR8 RICE SEEDLINGS GROWN IN 3 SOILS FROM THE IVORY COAST

(Rinaudo et al 1971)

Soils	Texture (percentage)			Total C content (10^{-3})	Total N content (10^{-3})	C/N	pH	ARA 1/
	Clay	Silt	Sand					
Dabou	63	32	1.5	46.95	3.00	15.6	6.2	33
Abengourou	30	38	28	31.75	2.57	12.8	6.5	9
Yamoussokro	27	28	44	17.80	1.51	11.8	6.9	19

1/ ARA expressed in terms of nanomoles C_2H_4 per g dry rhizosphere soil per hour.

3.3. Influence of Organic Matter Additions on Asymbiotic Fixation in the Soil

It is well known that adding organic energy sources to soil especially carbohydrates such as glucose or starch, promotes asymbiotic nitrogen fixation, provided no limiting factor (e.g. phosphorus deficiency) impedes the activity of the diazotrophic micro-organisms. When artificial energy sources like sugar, are replaced by natural plant residues N_2 fixation occurs only if the type of organic matter used has a high C/N ratio and is easily decomposed.

High nitrogen fixation rates obtained in the laboratory by incorporating such organic energy sources have seldom been reported in the field because the amount of organic matter incorporated in such conditions is usually much lower (0.1 % instead of 1%) in order to avoid the depletion of organic nitrogen which would be detrimental to the plant. One should add that it is difficult to evaluate N balances in the field because of the magnitude of sampling errors and the occurrence of uncontrollable factors. Despite these limitations, Abd el-Malek (1971) obtained substantial nitrogen gains by incorporating additional plant residues into different Egyptian soils, which are characterized by their low organic content and their richness in calcium carbonate. Unfortunately, no data was given regarding the plant yields.

A study carried out in Senegal by Beye (1977) showed that ploughing straw into waterlogged paddy soil (sol gris) significantly increased the yield of paddy and the N content of the rice plants, which suggests that the incorporated straw had stimulated nitrogen fixation and subsequently increased the amount of nitrogen available to the plant. This favourable effect on rice yields was not found when experiments were performed using a different soil type (sandy paddy soil). This discrepancy could be attributed to the fact that the latter soil type harbours a much less active N_2 fixing microflor. In the soil of the IRRI Research Station, Watanabe (1975) it was found that the N_2 fixing activity was markedly enhanced in leftover rice stubbles.

Studies reported above are incomplete since they were carried out either by microbiologists or by soil scientists and not by interdisciplinary teams, but they suggest that the incorporation of organic matter stimulates N_2 fixation and could possibly increase the crop yield in some soil types (e.g. Senegalese sol gris). Further studies are needed in order to investigate whether the yield increase is actually due to N_2 fixed at the expense of these residues, acting as a source of energy for soil diazotrophs.

3.4 Azolla and Blue-green Algae Utilization in Rice Culture

The agronomic significance of the Azolla-Anabaena association, which has been reviewed by Moore (1969) and more recently by Silvester (1977), is now well known. Pot experiments in Indonesia showed that inoculating rice with Azolla markedly increased rice production and suggested that fixed nitrogen was absorbed by rice after the death of Azolla (Table 5).

At the present time, Azolla is often used as a green manure. It is introduced into the paddy field, allowed to grow and cover the water surface, then ploughed in when it is dead. Azolla may be grown at the same time as rice or in the interval between two rice crops or a dry, irrigated crop. Recent field trials carried out at IRRI's station in Los Banos showed that "Azolla that grow in field plots for 20 to 23 days accumulated 24 kg N per ha. From October to January (106 days) five crops of Azolla were harvested, accumulating 120 kg N/ha." (Watanabe 1977). Inoculating a plot with Azolla at the time of transplanting resulted in an increase in grain yield of 13% over a control plot (Watanabe 1977). This experiment and other trials suggest that the beneficial effect of Azolla may be due not only to the release of nitrogen in the soil but also to other processes which are largely unknown. Thus Kulasooriya and de Silva (1977) found that the Azolla treatment outdid the urea treatment in percentage of filled grains. "Azolla-plus-fertilizer registered 132% as many filled grains per panicle as the control; the urea treatment registered 95%, which indicates that Azolla could act by reducing sterility." Since optimum growth conditions of Azolla are not very well known, further studies are needed in order to solve the problems regarding Azolla inoculation of paddy fields on a large scale. One must keep in mind the fact that limiting factors which cannot be controlled, may impede this application. Thus tempteratures above 31°C are known to inhibit the growth of Azolla (Watanabe 1977), restricting its use to some climatic conditions.

Table 5 EFFECT OF AZOLLA ON GROWTH AND NITROGEN CONTENT OF RICE PLANTS WITH AND WITHOUT A 4-DAY DRY PERIOD IN WHICH AZOLLA PLANTS DIED

(Silvester 1977)

Treatment	Water Supply	Rice Production (per pot) Dry wt.(g)	Total N (mg)
Control minus Azolla	Continuous	36.9	221
	Dry period	40.0	240
Half Azolla	Continuous	51.5	301
	Dry period	51.0	309
Full Azolla	Continuous	43.3	316
	Dry period	48.9	465

The inoculation of rice with blue-green algae has been performed extensively in Japan and in India. In India algae inoculation was shown to have a significant positive effect on rice yields even with high rates of fertilization (Venkataraman 1972). The development of algalization is desirable, but it may be limited, as is Azolla inoculation, by uncontrollable environmental conditions. Thus Roger and Raynaud (1977) have shown that high light intensities, which are often encountered in semi-arid situations, as in Senegal, may inhibit the growth and nitrogen fixing activity of blue-green algae.

3.5 Promoting N_2 Fixation in Composts

During the composting process of plant residues or various objectional wastes, nitrogen losses occur through denitrification and leaching. The question arises as to whether one could balance such losses by promoting N_2 fixation at a given stage of the decomposition process. Exploring such a possibility is most desirable, especially in situations where nitrogen fertilizers are expensive.

4. CONCLUSION

It is very difficult to discuss the effect of soil organic matter on biological N_2 fixation for at least three reasons:

i. organic matter is not a defined compound but is made up of a host of different heterogeneous materials mostly comprised of plant residues and their decomposition and re-synthesis products;

ii. organic matter may directly and/or indirectly affect the N_2 fixation process;

iii. the effects of organic matter depend critically on actual environmental conditions

Discrepancies in results reported in the literature may be attributed to the heterogeneity of the composition or organic matter. An example has already been given pertaining to the effect of straw. Table 6 shows the main hypotheses which could explain most of the direct or indirect effects of organic matter on N_2 fixation.

Table 6 HYPOTHETICAL MECHANISMS BY WHICH SOIL ORGANIC MATTER CAN DIRECTLY OR INDIRECTLY AFFECT N_2 FIXATION

Hypothesis Number	Organic matter as	Direct effect	Indirect effect through the plant
1	Source of anti-microbial compounds or growth factors for micro-organisms	+	
2	Factor of stimulation or inhibition of plant growth		+
3	Agent of improvement of physical soil properties: microstructure, aggregation, water storage	+	+
4	Source of organic or inorganic nutrients (especially nitrogen)	+	+
5	Buffer, ion exchange material, agent of prevention of phosphate fixation	+	+

First, organic matter can have a direct and specific effect on diazotrophs acting as a source of anti-microbial compounds or as a source of growth factors (hypothesis 1).

Second, organic matter can also have a sepcific effect on plants, organic compounds "being taken up by the plants through the roots and participating in the plant's metabolism" (Flaig 1972), thus promoting or inhibiting plant growth (hypothesis 2).

Third, organic matter, particularly in tropical conditions, plays a major role in inproving physical and chemical soil properties, thus affecting the plant and associated diazotrophs (symbiotic and rhizospheric N_2 fixation) or the diazotrophs alone (asymbiotic N_2 fixation) (hypothesis 3-4-5). In semi-arid soils, the favourable effect of organic matter on the water retention characteristics of soils (Charreau 1974) should theoretically enhance N_2 fixation, especially during drought spells since soil humidity is one of the major limiting factors for N_2 fixation (cf. section 2.1.1). A good soil aeration is a prerequisite for symbiotic N_2 fixation; improvement of soil structure should result in an increase of N_2 fixation. Likewise, improvement of chemical properties such as the prevention of phosphorus fixation by organic matter (Charreau 1974) should also favour N_2 fixation processes.

Effects of organic matter on N_2 fixation have not been clearly demonstrated up till now. This is because the problem is highly complex. Such complexity has obviously rebuffed most researchers. However, in spite of such difficulties, research in that field should be developed because agronomic observations and preliminary experimental data clearly suggest that organic matter plays a prominent role in the expression of the N_2 fixing ability of the different systems. Organic matter management seems a promising means of directly or indirectly stimulating N_2 fixation, thus saving nitrogen fertilizers.

Recent advances in the field of soil microbiology and in that of modelling biological processes (cf. Schmidt et al 1977) will probably facilitate the development of such urgently needed research . However, one must bear in mind the fact that these investigations should always be carried out by multidisciplinary teams involving not only soil microbiologists, but also other groups of soil scientists, plant physiologists and, of course, agronomists.

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Paper 10

EFFECT OF NITROGEN FERTILIZER (UREA) AND ORGANIC AMENDMENTS (COMPOST) ON THE STABILIZATION OF ORGANIC MATTER IN A MILLET MONOCULTURE IN SEMI-ARID TROPICAL CONDITIONS

C. Feller [1] and F. Ganry [2]

Summary

Techniques used to increase cereal production must satisfy two objectives: firstly, improvement of yield and nutritional value and, secondly, maintenance of soil fertility. Taking into account both aims, a four-year experiment was carried out at Bambey (Senegal). Organic manuring (composted millet straw) and mineral fertilizer including nitrogen were applied every year to a culture of millet grown on the same sandy soil.

Results on the soil productivity aspects of this experiment (yields, nutritional value) were presented by Ganry (1977), and the soil organic matter stabilization study is the subject of this paper.

A very simple fractionation method carried out on large amounts of soil made it possible to separate the soil organic matter into three parts:

- plant residues of a size larger than 2 mm (ML1 fraction);
- plant residues of a size smaller than 2 mm (ML2 fraction);
- humified organic matter (FL fraction).

The authors show that it was not possible to improve the stock of soil organic matter unless organic manuring and nitrogen fertilizer were supplied together. The increase in carbon level is due to the carbon contained in the ML2 and FL fractions and varies in proportion to the quantity of nitrogen fertilizer.

In the absence of nitrogen fertilizer, compost supplied alone did not result in an improvement of soil organic matter content.

In the absence of organic amendments the supply of nitrogen fertilizer did not increase soil organic matter content irrespective of rate of application.

1. INTRODUCTION

The rapid degradation of soils in the dry tropical zone, following the clearance of natural vegetation and the introduction of cultivation is well known. [3] The maintenance and/or a lasting improvement of the fertility of these soils is an essential aim of tropical agronomic research. Research undertaken for some years by IRAT to achieve this objective (Pichot 1975) has shown the importance of organic matter in maintaining soil fertility and has led to the search for techniques aiming at increasing and stabilizing the organic matter content of cultivated soils in the tropics.

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[3] In Senegal, see: Bouyer (1959), Dommergues (1956), Fauck et al (1969), Feller and Milleville (1976), Siband (1974).

In the specific case of sandy soils, organic matter is a key factor for improving soil biological and physical properties, its reserve of nutrients and thus increasing the yield more than by the use of chemical fertilizers.

With this in mind, IRAT set up in various African countries (in 1971 in Senegal) a series of experiments called "Experiments on the Specific Role of Organic Matter" to investigate the application of different amounts of nitrogen with or without an organic matter amendment.

The results of experiments set up at CNRA, Bambey (ISRA, Senegal) to study the effects of the application of millet straw compost, in the presence of different doses of nitrogen fertilizer, on a continuous culture of millet for four successive years are reported in this paper.

One part of this study (Ganry 1977) will deal with the soil productivity, both from the quantitative (yields) and the qualitative standpoint (nutritive aspect of the crops). Thus, one should be in a better position to evaluate the immediate and less immediate effects of cultivation techniques. The soil organic matter balance will be considered after four years of experiment, thus investigating the middle term effects of this fertilization.

2. MATERIAL AND METHODS

The experiment was conducted at CNRA, Bambey, on a slightly leached ferruginous tropical soil (Dior soil). The annual average rainfall between 1972 and 1975 was 430 mm. The test crop was millet (Pennisetum typhoides Hubb and Staff). From 1972 to 1974 the cultivar Souna III was used, this millet being characterized by its traditional structure. In 1975, a newly selected millet variety was used which is characterized by a shorter stalk and a shorter time to maturity (75 days instead of 90 days). Treatments were as follows: 0, 30, 90, 120, 150 kg N/ha with or without millet straw compost.

The compost was made in a pit from finely cut millet straw (residues of about 2-5 cm in length). Beds of damp straw were interlayered between thin beds of manure, which served as a starter. Composting lasted from 4 to 6 months and the C/N ratio decreased from about 35 to 20.

The compost, applied each year at the end of the cycle (October), was buried 20 cm deep together with the residues of the previous crop (millet stalks not removed from the field) at the rate of 11.0, 15.0, 9.3 and 9.3 t/ha (dry matter) for the years 1971, 1972, 1973, 1974 respectively.

Plot sizes were 6 x 20 m, arranged in blocks, each plot subdivided into two sub-plots A and S (with or without compost) with six replications.[1] The elements P, K, and S were applied each year at the rate of 100 kg/ha of P_2O_5 and K_2O and 10 kg/ha of S. Oligo-elements, in the form of nutramine, were applied at the rate of 5 kg/ha in the first year (1972). Nitrogen was applied as urea three times during the course of the growth cycle (1/5 at sowing, 2/5 at thinning (10th - 15th day) and 2/5 during stem elongation).

Soil samples were taken from sub-plots which received compost and different amounts of nitrogen fertilizer. Their principal characteristics are summarized in the following table.

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[1] A indicates with compost
S indicates without compost

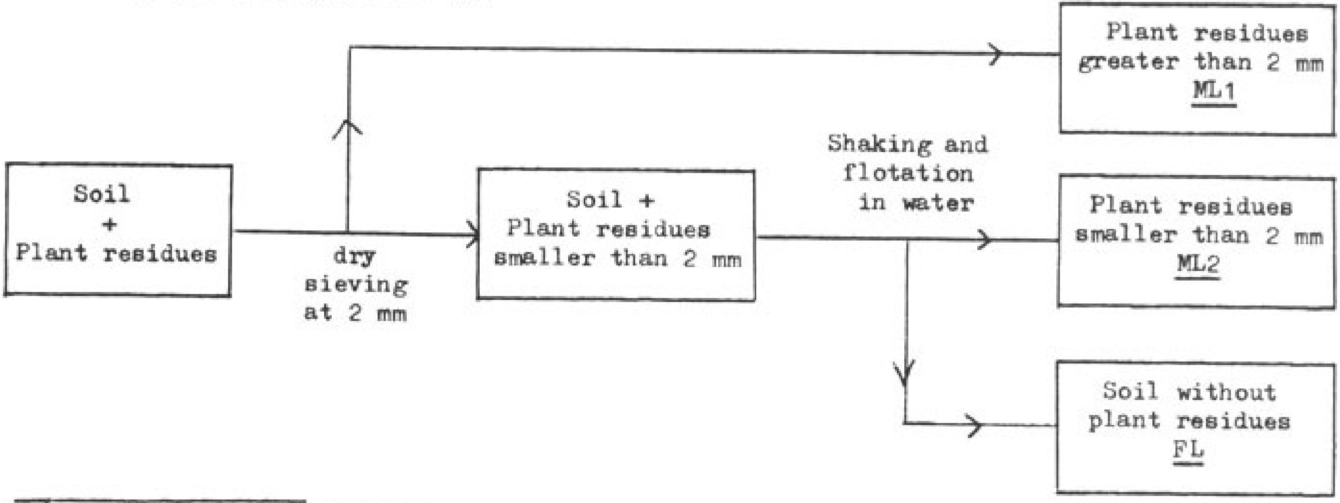
Treatment [1]	Mineral maintenance fertilizer (P,K,S)	Nitrogen fertilizer kg/ha	Compost
1 A	No	0	Yes
1 S	Yes	0	No
2 A	Yes	0	Yes
2 S	Yes	0	No
4 A	Yes	60	Yes
6 A	Yes	120	Yes
7 A	Yes	150	Yes
7 S	Yes	150	No

In December 1976, when this work was carried out, no compost was added during the ploughing following the harvest, so that the samples examined would make it possible to compare four years of cropping with, and without addition of compost. Because of the technique of deep placement used (ploughing), the distribution of the organic matter in the soil was very heterogeneous, and a preliminary statistical study to establish the size of the samples was necessary for each treatment carried out. This showed that 60 spade samples (about 240 kg of soil) at a depth of approximately 20 cm, were needed to estimate the weight of plant residues of more than 2 mm length (<u>ML1</u> fraction) with an average standard error of approximately 16% (P = 0.05).

Each soil sample was sub-divided into:

- plant residues of a size greater than 2 mm (<u>ML1</u> fraction);
- plant residues of a size smaller than 2 mm (<u>ML2</u> fraction);
- soil cleared of ML1 and ML2 fractions and called FL fractions (organo mineral fraction or "linked-fraction").

The results, for each organic fraction, are expressed in C ‰ of the weight of the soil (Appendix 1).



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[1] A indicates with compost
S indicates without compost

3. RESULTS

Fig. 1 shows the actual variations of the carbon content and Fig. 2 the variations of the different fractions of treatments with compost in relation to the total carbon content of the treatments without compost (controls).

3.1 Relative Proportions of the Different Fractions

ML1 fractions represent only 2–3% of the total carbon as compared to 20–35% for ML2 fractions and 60–80% for FL fractions.

Although the addition of organic matter was made in the form of plant residues of a size greater than 2 mm (ML1)[1], these particles disappeared almost completely during the rainy season and contributed, at their initial size, very little to the carbon balance.

3.2 Evaluation of the Different Fractions as a Function of the Treatments

Observation of Figs. 1 and 2 shows that:

i. For the controls without compost, the percentage carbon of the different fractions remained constant regardless of the amounts of nitrogen and mineral fertilizer added (treatments 1S, 2S, 7S).

ii. The compost enriched the soil in carbon in all cases other than in treatment 1A where decreases of the FL fraction and the total carbon CT as compared to the control were observed (Fig. 2).

iii. A marked effect was noted of nitrogen on the ML2 and FL fractions of the treatments with compost. The variation of the carbon was proportionate to the amount of nitrogen applied. The increase went up to 110% for the amount of 150 kg/ha and represented 100% for 90 kg N/ha which is the amount often used in fertility studies for the soils of CNRA of Bambey. On the other hand, there was no variation for the ML1 fraction and the increase in relation to the control was very slight.

iv. Even without nitrogen, the compost added to the maintenance mineral fertilizer (P, K, S) caused an increase of 25% of the total carbon (see Fig. 2, treatment 2A). However, the addition of compost in the absence of mineral and nitrogen fertilizer (see Fig. 2, treatment 1A) induced a notable decrease of the FL fraction and hence of the total carbon (ML1 and ML2 fractions remained more or less constant).

4. DISCUSSION AND CONCLUSIONS

Within the framework of this experiment, the improvement of the soil organic matter appeared to require an organic amendment (in this case compost). Nevertheless, this must be combined at least with a maintenance mineral fertilizer, otherwise the opposite effect to that expected is observed, i.e. a decrease of the total carbon.

The enrichment in carbon seemed to increase when deep placement was combined with large additions of nitrogen. Several hypotheses may be considered in explanation of this result, in particular:

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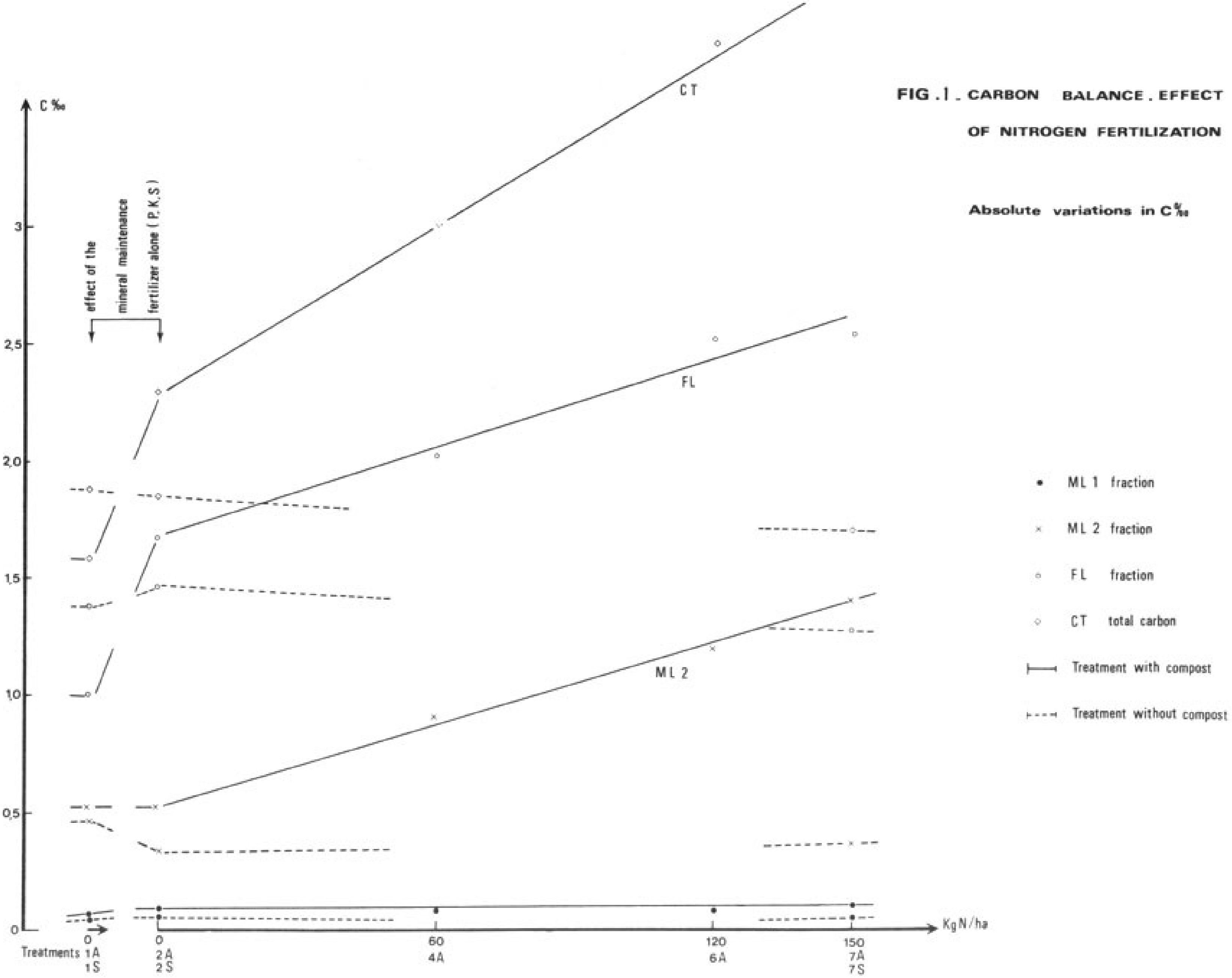
[1] In the compost used organic residues of a size greater than 2 mm represents 90% of the total organic matter and only 10% is present in the form of organic particles of a size smaller than 2 mm.

FIG. 1. CARBON BALANCE. EFFECT OF NITROGEN FERTILIZATION

Absolute variations in C‰



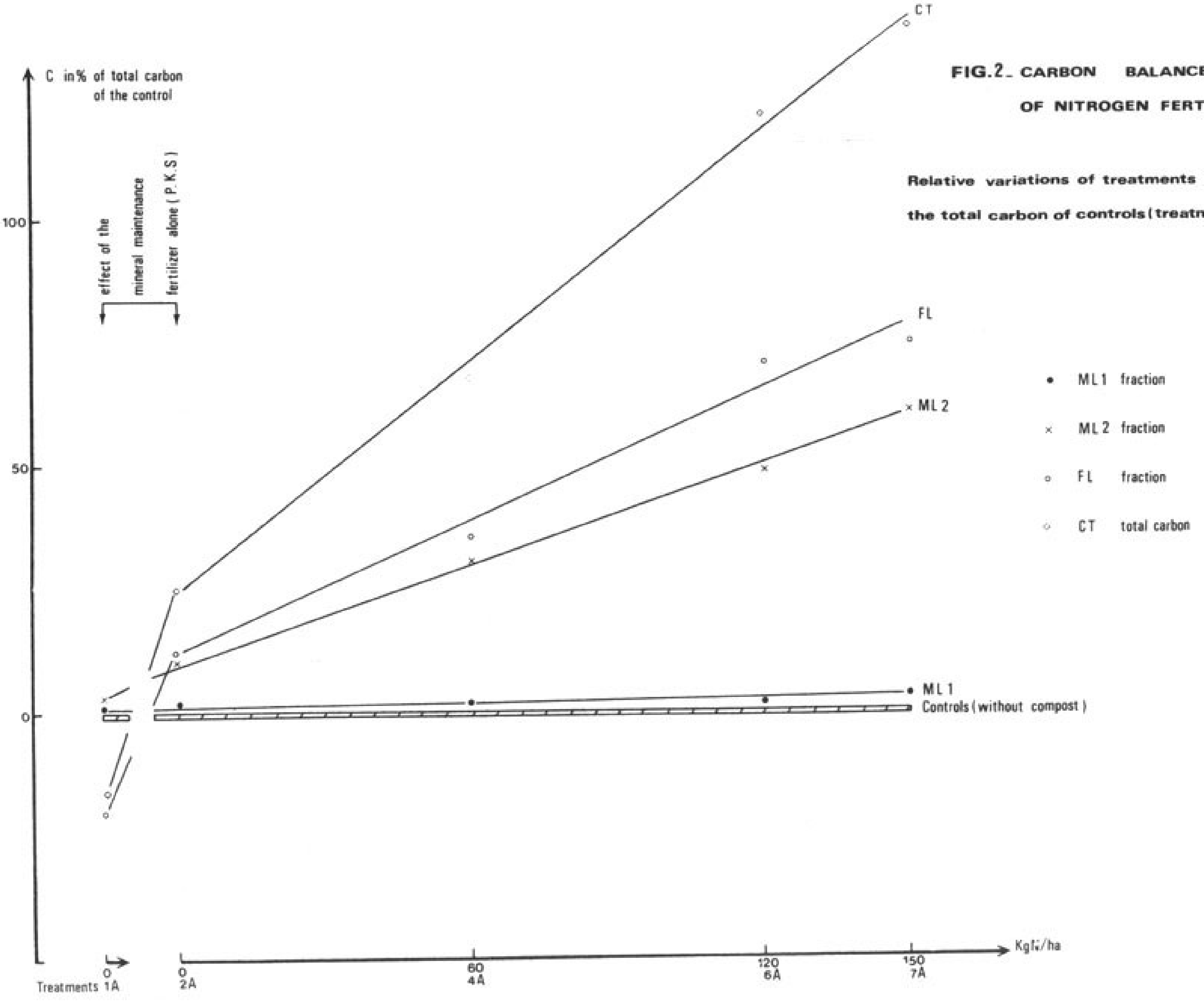


FIG. 2 _ CARBON BALANCE . EFFECT OF NITROGEN FERTILIZATION

Relative variations of treatments with compost in % of the total carbon of controls (treatments without compost)

i. The nutritional role of the compost

In the absence of nitrogen and of mineral fertilizer, the compost acts as a reserve of nutritive elements first for the microflora and secondly for the plant 1/. Its humification role is then negative (treatment 1A) or slight (treatment 2A). On the other hand, in the presence of high mineral additions, the nitrogen requirements of the microflora are partly met by the fertilizer and the evolutionary process of the compost is then directed towards humification rather than towards mineralization.

ii. The protective role of nitrogen

The presence of nitrogen allows the synthesis of stable humic compounds on the surface or even within the plant residues, which may have a protective effect in relation to the mineralizing action of the microflora.

iii. The increase of the root system

The simultaneous presence of nitrogen and of compost increase plant growth, in particular that of the root, and thus indirectly permits an increase of organic matter in the soil in the form of root residues.

The fractions which benefit are the two fractions most humified, ML2 and FL, since the fraction ML1 hardly appears in the carbon balance.

These preliminary results, relatively spectacular (multiplication by two of the carbon levels for high amounts of nitrogen), under tropical conditions where the mineralization processes are intense, lead to at least three questions:

a. For a given agricultural practice (nature of vegetation and agricultural techniques) how stable is the newly formed organic matter? In other words, what is the time necessary for the return to the original organic level if all organic amendments are stopped?

b. What is the optimum solution of $\frac{\Delta \text{ O.M.}}{\Delta t} = f\ (C,N)$, which allows for increasing the level of organic matter in a soil from its present point A to a given point B previously defined by economic and/or agronomic considerations.

c. Can the same aims be attained with other organic residues besides compost. Also, what is the role of these residues on the evolutionary processes of organic matter?

The next stage of this study should make it possible to answer, at least partially, these questions.

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APPENDIX I.

FRACTIONATION OF SOIL ORGANIC MATTER

Plant residues of a size larger than 2 mm: ML1 fraction (free organic matter No. 1)

The whole soil sample, approximately 240 kg, is air-dried and passed through a 2 mm sieve. The fraction remaining on the sieve is then cleared of sand by flotation in water, dried at 50° for four days, weighed, then finely ground (ML1 fraction).

The soil humidity is determined by oven-drying at 105° for 24 hours and the ash content by oven-calcination at 750° for 4 hours.

The carbon content is measured in a carmograph and expressed as a thousandth part of the weight of the soil.

Plant residues of a size smaller than 2 mm: ML2 fraction (free organic matter No. 2)

2 kg of soil sieved at 2 mm and cleared of ML1 fraction were decanted by successive fractions in about 10 litres of water. The plant residues of a size smaller than 2 mm were then separated by flotation [1], dried at 50° for four days, then finely ground (ML2 fraction). They are then treated in the same way as ML1.

Humified fraction of organic matter: "fraction liée FL"

The soil residue after separation in water of ML2 [2] is dried, ground at 0.5 mm and, on this fraction (FL), the carbon content is determined.

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[1] By shaking the soil in water and by decanting several times, it is possible, in these sandy soils, to recuperate almost the whole of the plant residues less than 2 mm length, even if their density is greater than 1.

[2] When ML2 is separated, the clay fraction remaining in suspension in the water is flocculated by addition of HCl at 1/2 up to 2.0. After decanting, centrifuging and washing in water, this fraction is recovered and added to the soil residue.

Paper 11

THE IMPORTANCE OF CULTURAL METHODS TO INCREASE THE QUANTITY OF NITROGEN (N_2) FIXED BY A GROUNDNUT CROP IN THE SUDANO-SAHELIAN ZONE OF SENEGAL

F. Ganry

1. INTRODUCTION

The decrease of the quantity of N_2 fixed by a leguminous crop may be the result of limiting factors or constraints which affect: either the vegetative growth, and thus have an indirect effect only on the N_2 fixing activity; or the N_2 fixing activity of the legume Rhizobium system with or without a depressive effect on yield; or both phenomena together affecting both vegetative growth and the N_2 fixing activity.

To overcome these constraints, cultural methods are proposed that can be applied to Senegalese agriculture. These cultural methods which are either applied singly or integrated in a cropping system will thus be capable of improving or maintaining the level of atmospheric nitrogen fixed biologically by a groundnut crop in the environmental conditions of the sandy soils of the Sudano-Sahelian zone.

2. APPROPRIATE CULTURAL TECHNIQUES TO REMOVE CONSTRAINTS

These techniques are essentially:

- crop varieties with an appropriate vegetative cycle;
- early seeding;
- use of mineral fertilizers;
- soil tillage, soil turnover;
- organic and calcium amendments;
- inoculation with rhizobium.

The study of rotation, although of importance, is not discussed in this paper.

2.1 Crop Varieties with an Appropriate Vegetative Cycle

Studies of the periodicity of rainfall have been the basis of selection of a cultivar suited to a particular region (Dancette 1977). The following groundnut varieties, already selected and generally applied through extension services, are available:

- growing period of 90 days, drought resistant;
- growing period of 105 days, drought tolerant;
- growing period of 115 - 120 days, drought resistant;
- growing period of 120 days;
- growing period of 125 days.

2.1.1 The problem of drought resistance in the Central-Northern Zone (Sudano-Sahelian Zone)

The adaptation to drought of the 90 day selection has been confirmed at the station and in scattered field trials giving yields of unshelled groundnuts of 3 000 kg/ha in 1975 and 2 500 kg/ha in 1976. Physiological work has determined a cultivar of a medium late growing period, exceptionally resistant to drought, giving yields at the station of unshelled groundnuts of 3 600 kg/ha in 1975 and 3 200 kg/ha in 1976 (Bockelee et al 1974 and Gautreau 1977).

2.2 Early Seeding

The earliest date for planting seeds of pearl millet and groundnut in the north and middle region of Senegal should be before the first rain for millet (in dry soil) and just after the first rain for groundnut (in wet soil). The later the planting date, the greater the yield decrease.

The time of planting groundnut just after the first rain depends upon the agricultural plan of work of the farmstead, the acreage to be planted and upon the number of animals available for working. For this reason, for example, about 50% of the planting in the region of Sine-Saloum is carried out at a later date, and in 1973 it caused a loss in yield of about 50 kg/ha even though conditions were suitable for seeding at the time (i.e. the first fifteen days in July).

2.3 Mineral Fertilizers: the Importance of Nitrogenous Fertilizer as a Starter

It has not yet been clearly established that a nitrogenous starter has an assured positive effect. The hypothesis presently established and based on the results of two years of experimental work at Bambey is that the effect of the starter nitrogen depends on the distribution of rains and on the rainfall received at the beginning of the season (Ganry et al 1976). A deficit in rainfall early in the season seems to depress the effect of the starter nitrogen on N_2 fixation. The lower N_2 fixation would be compensated by a higher absorption of soil nitrogen and fertilizer nitrogen which could explain the fact that yields do not decrease proportional to the diminished nitrogen fixation from the air. On the other hand, well distributed and sufficient rainfall at the beginning of the growing cycle would bring about a positive effect on the parameters of N_2 fixation, but without correspondingly affecting yields. 1/ On the basis of this finding, which is still not confirmed, and by the fact that a yield increase due to the nitrogenous fertilizer would not be derived from a higher N_2 fixation but from the organic nitrogen reserve in the soil, it would be preferable not to recommend the application of nitrogen when seeding groundnuts. However, we feel it is not necessary to modify the fertilizer recommendation used in agricultural extension, i.e. the application of a complete compound fertilizer, the most important one being 8-18-27, applied at the rate of 150 kg/ha. On the contrary, later or split application after seeding would have a negative effect on the nitrogen balance, even if yields would be increased.

2.4 Soil Tillage: Ploughing

The positive effects of ploughing on the yields of groundnuts can be classified into three groups (Nicou 1977):

- water economy,
- mineralization of organic nitrogen,
- symbiotic activity.

Hydrological constraints directly affect the N_2 fixing activity which is strongly reduced below a humidity of 4% (pF4.2 = 2%) in a soil of the "dior" series

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1/ It appears that the application of nitrogenous fertilizer at the beginning of the growing cycle can have a positive or negative effect on N_2 fixation, but without correspondingly effecting yields.

at Bambey (Ducerf 1977 unpublished). Although the groundnut plant does not show wilting symptoms, under these conditions the plant takes up nitrogen from the soil to the detriment of the soil reserves, since N_2 fixation is strongly reduced. In 1976, a year of little rainfall with a dry spell during the post-flowering period, we found at Bambey, that groundnut plants took out of the soil reserve 80% of its nitrogen at a production level of 1500 kg/ha of unshelled nuts whereas in a normal year this supply from the soil does not exceed 30%. This emphasizes the second positive aspect of ploughing, i.e. the stimulation of the mineralization of the soil organic nitrogen, as shown in Figure 1.

It appears that this mineralization ensures the nitrogen supply to the plant during periods of deficient N_2 fixation. Whereas mineralization acts favourably on the vegetative vigour of the groundnut plant, indirectly it also has a positive action on its potential for N_2 fixation during the following period when soil humidity has again become favourable for N_2 fixation.

The effect of ploughing on N_2 fixing activity is especially high at the beginning of the growing cycle as shown by the fixation curves obtained with the acetylene reduction method (Fig. 2). The combined results obtained in 1976 confirmed these findings, since at the 62nd day the fixation had practically tripled on the ploughed plot (74 000 nanomoles C_2H_4 per hour/plant against 27 000 on the control plot), a result which corresponded to that obtained with inoculation. The phenomenon is especially striking on exhausted sandy soils with low biological activity which partly explains the spectacular effects of ploughing on groundnut yields in the north and centre-north of Senegal.

2.5 Organic and Calcium Amendments

The restoration of organic material to the soil should play an amendatory role because of the low buffer capacity and the poor physical chemical condition of the "dior" type sandy soils, but it should also play a role as a nitrogen fertilizer which is most important for maintaining the equilibrium of the nitrogen balance in the millet-groundnut association.

In the case of intensive agriculture - considering an optimum N_2 fixation capacity of 70% of the total nitrogen content of groundnuts and in view of the nitrogenous fertilizer applied and also of the nitrogen losses - the restoration of the cereal straw, composted or not, is essential for the maintenance of the equilibrium of the nitrogen balance.

In the case of agriculture of medium intensity, it is thought that the restoration of organic material is not strictly necessary as stated before, but becomes optional depending on environmental factors such as climate (especially soil moisture) and edaphic factors (pH and nutritional elements other than nitrogen) which would allow N_2 fixation beyond a certain level (80 - 90% of the total nitrogen but the exact percentage is still to be determined). The effect and extent of mineral fertilization would also depend on these factors. Indeed, the groundnut crop contributes nitrogen of symbiotic origin to the agro-system through organic residues remaining in the soil (roots and parts of leaves) and probably also by root exudates.

In this connection, our experiments have shown that a soil in which no organic matter was incorporated, except the crop residues remaining in the soil after harvest, could have restored to it between 17 and 30% of the symbiotically fixed nitrogen (Nicou 1977).

In the case of exhausted soils, the incorporation of organic matter, and especially of farmyard manure, has a highly favourable effect on yields. These better yields are the result of increasing N_2 fixation (Wey and Obaton 1977).

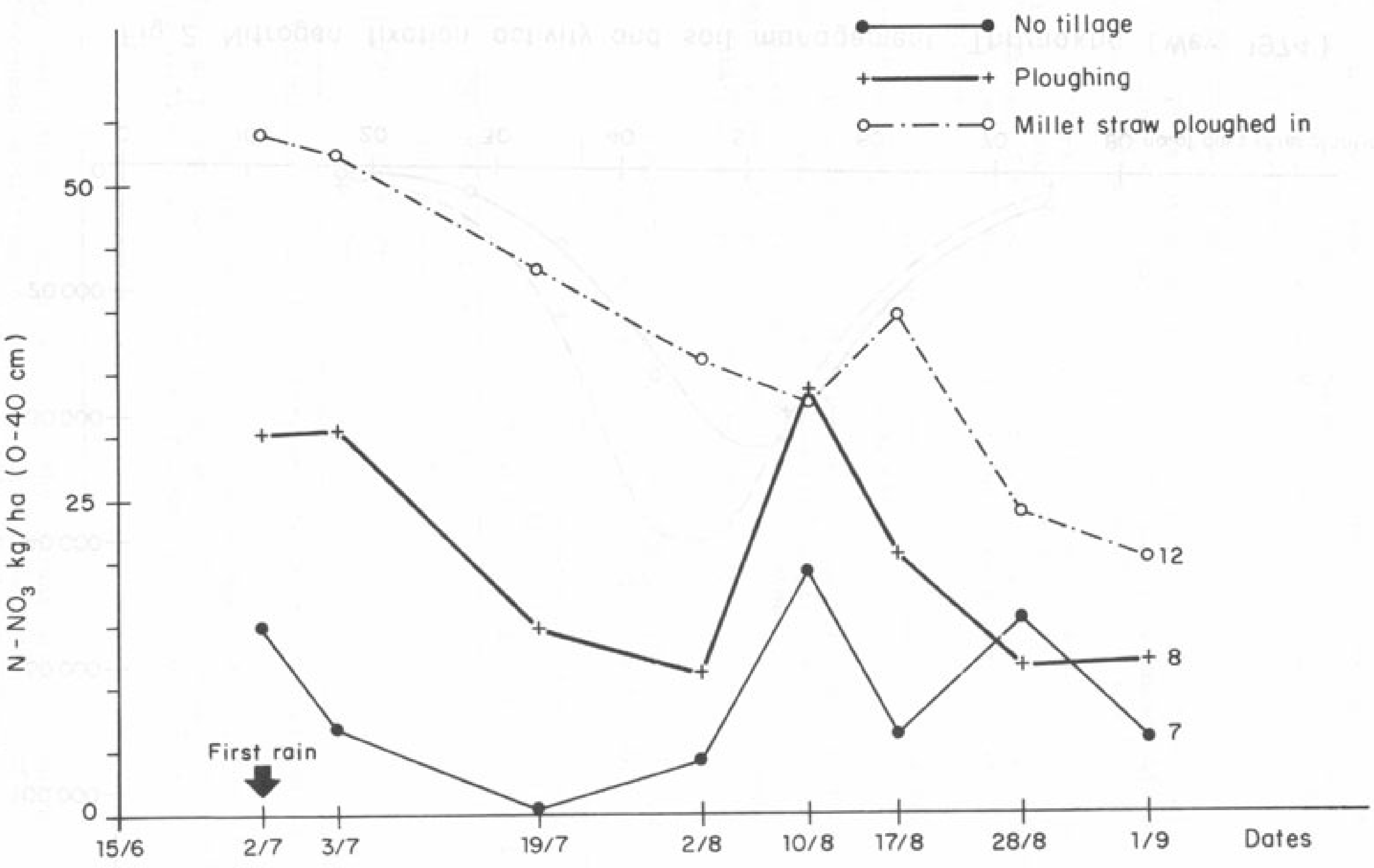

Fig. 1 Mineralisation of organic nitrogen and soil management
(Under a crop of groundnut, Bambey 1972)

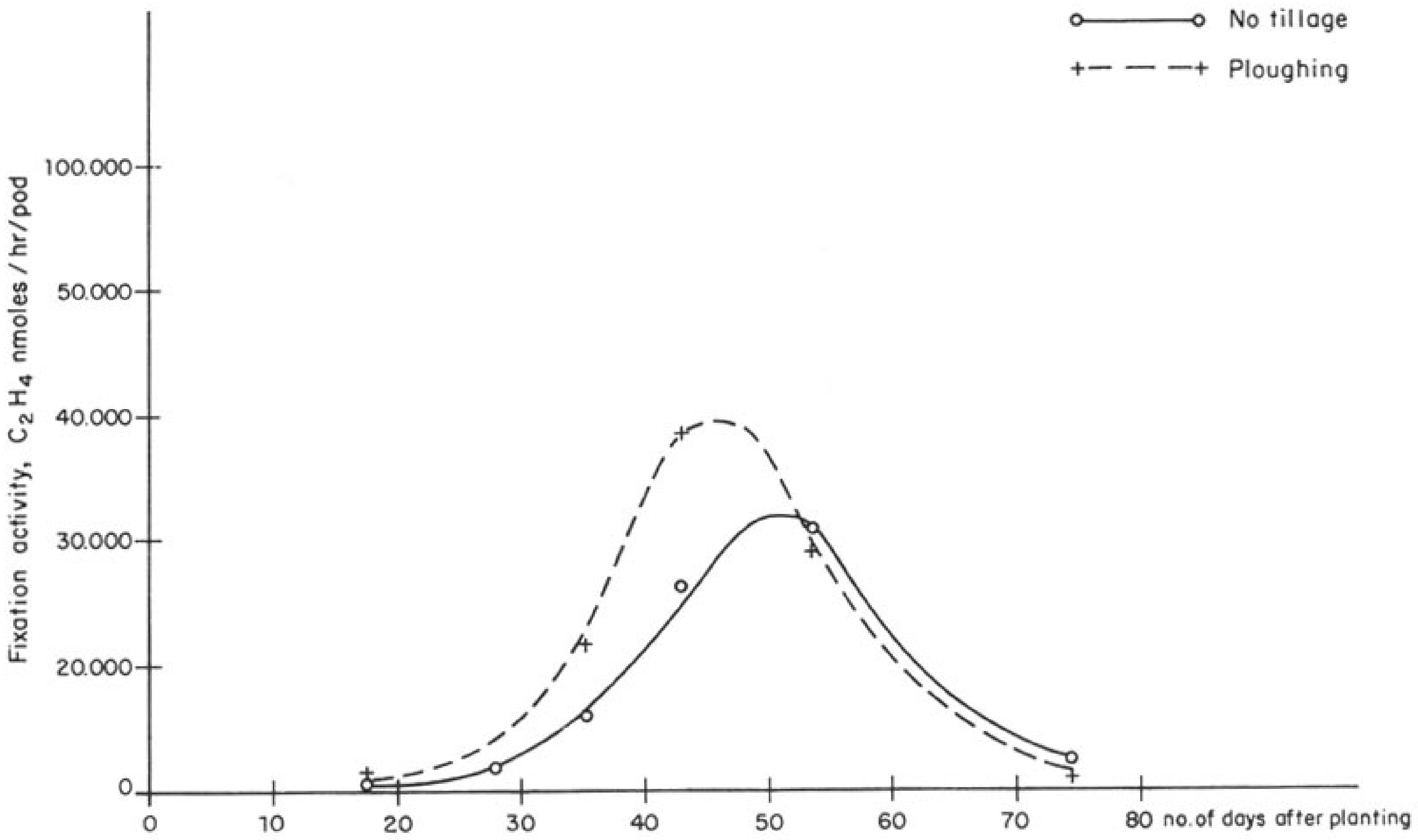

Fig. 2 Nitrogen fixation activity and soil management. Thilmakha (Wey, 1974)

Liming (calcium amendments) will be required in soils of a pH lower than 5.5 (water). Soils which can be considered as acid are not really adapted for the cultivation of groundnuts (Blondel 1970). Pieri has shown that the liming requirements of acid soils should be calculated on the basis of the level of Al^{+++} saturation which is a much more precise indicator for groundnut yields than the pH (water) (Pieri 1976). In fact that indicator is four times more precise. It is thought that the requirements are between 100 and 500 kg/ha of CaO, depending on soil type and other environmental conditions.

2.6 Rhizobium Inoculation

It is not enough just to introduce an active strain into the soil to induce N_2 fixation, but it should also be able to survive under unfavourable environmental conditions (soil acidity, temperature, etc.) and to infect the roots.

At research level, inoculation is at present practised by spraying the liquid inoculum into the soil and then incorporating it by superficial hoeing or ploughing. The question is whether this method would be acceptable at the average farmer level. In that respect, it can be considered similar to the application of herbicides.

Considerable research work is still required in the field of lyophilization, use of compost, granulated inocula, etc.

Even if the results of groundnut inoculation so far obtained do not show substantial yield increases (the additional yield seldom exceeds 200 kg of unshelled groundnuts per hectare), they do show a positive action on N_2 fixation which is an important factor for the economy of soil nitrogen. Table 1 illustrates an IAEA/ISRA experiment carried out at Bambey.

Table 1 EFFECT OF INOCULATION ON THE MOBILIZATION OF NITROGEN ORIGINATING FROM N_2 FIXATION AND FROM THE SOIL

		Nitrogen immobilized in kg/ha (by a groundnut crop)		
		Total N	Fixed N	Soil N
1975	Non inoculated	103	67	33
	Inoculated	118*	84*	32
1976	Non inoculated	77	16	57
	Inoculated	77	26*	49

* Significant P 0.05 in comparison with the non-inoculated control.

If we take the kg of soil nitrogen absorbed as a unit of energy cost 1/ for the protein production of a groundnut field, a rapid calculation shows that inoculation reduced the cost of groundnut protein by 16% in 1975 and by 17% in 1976.

1/ Energy costs: theoretical approach for the evaluation of the energy investment; example: - nitrogenous fertilizer is expensive for a given production of vegetative matter. In the present case the organic nitrogen in the soil is considered as an energy capital which can be financially evaluated by considering its value in the form of fertilizer nitrogen.

3. CONCLUSION

The analysis of agronomic and climatic constraints for groundnut production has shown the importance of:

i. unforeseeable hydrological constraints, which bring about a pronounced deficit in N_2 fixation as a first consequence;

ii. the foreseeable constraint concerning fertility, which gradually becomes a threat in traditional agriculture.

The most important manifestation of this decrease of fertility is the nitrogen deficiency which is attributed to the low nitrogen reserves in the soil (low level of organic matter) but also, and especially, to the soil acidity with its inhibitive effect on N_2 fixation, in the specific case of pH 5.5, which in turn aggravates the nitrogen deficiency.

Consequently, it appears that under conditions of water stress or soil acidity (pH 5.5), the quantity of N_2 fixed by a groundnut crop is reduced twofold because of the double action of depressive factors on (i) vegetative growth, and (ii) N_2 fixation.

Appropriate interventions should be primarily oriented towards the search for plant types able to resist or to avoid drought and its effects, and which are also possibly able to resist Al toxicity. Once the varietal choice is made, a certain number of techniques should be applied: soil tillage, soil amendments and inoculation.

It is important to know to what degree these techniques can be applied at farmer level.

There is little problem with the choice of varieties and early planting dates, since every farmer is aware of the risks he runs by not respecting the right choice.

As far as ploughing techniques, and organic and lime amendments are concerned, their application is most important because these measures condition soil productivity and the maintenance of the inherited capital represented by the soil. Unfortunately, there are difficulties with the application of these methods: few farmers plough their soil after the cropping season and thus do not restore organic matter by the incorporation of straw or farmyard manure.

The problem needs to be examined in its entirety, i.e. within the framework of cropping systems and of the integration of crop with cattle production.

The problem of liming is affected by the availability of liming material in the country. In Senegal, a factory is planned and it is hoped that the costs will not become an obstacle for the application of lime by the farmer.

As far as rhizobium inoculation is concerned, this technique has not yet gone beyond the stage of experimentation in Senegal.

Research continues aiming at its application by the average farmer. However, it is considered that for groundnuts, inoculation need not to be envisaged if the aforementioned cultural practices are rationally applied.

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Paper 12

SOME MICROBIOLOGICAL AND CHEMICAL EFFECTS OF THE DECOMPOSITION OF CROP RESIDUES IN IRRIGATED SUDAN SOILS

M.M. Musa [1]

Summary

Work related to the impact of crop residues from various rotations in the irrigated Gezira heavy clay/vertisols of the central Sudan was discussed. The energy-nitrogen relationships indicated the vast potential of mineral nitrogen immobilization for long periods in soils which are inherently low in nitrogen. Experiences with ploughing-in of various organic and green manures on direct and residual cotton yields are highlighted. Reconsideration of green manuring in newly planned intensified rotation may be desirable at this stage.

The beneficial effects of hoeing fallows a year before cotton cropping were amply demonstrated in terms of cotton yields and the long-term trends of soilorganic carbon and nitrogen which do not show significant differences. Being related in magnitude to the previous season's rains, it was thought that loss of N by way of weeds might be the cause of positive response to hoeing. Better nitrogen fixation and active mineralization of soil N in hoed fallows were postuled. A knowledge of the scientific explanation of the fallow hoeing phenomenon is needed.

1. INTRODUCTION

The area of the country with which this summary of work is concerned forms part of the "Central Clay Plain of the Sudan". This plain is generally characterized by Vertisols of deep cracking heavy clays (45-70% clay), well supplied with nutrients except nitrogen. Soil organic matter is however low, ranging between 0.45 to 0.95%. The prevailing climate of the area is semi-arid dominated by seasonal summer rains between July and September and ranging from 250 mm in the north, to 800 mm in the southern extremity of the flat plain. Ecologically, the vegetation merges from acacia desert, scrub and short ephemeral grass to tall grass acacia association.

In terms of land use however, the clay plain is the area where most irrigated and mechanized crop production is practised. The Gezira scheme with 2 000 000 acres, the Girba scheme of 500 000, the Suki of 80 000 and the projected Rahad of 800 000 acres are the main irrigation installations. Most of the sugar plantations fall in the area. The non-irrigated areas form the bulk both of traditional sorghum cultivation, and modern mechanized crop production schemes where sorghum, sesame and cotton are the main crops grown. Most of the information presented pertains to work conducted at the Gezira Agricultural Research Station, at Wad Medani and at Kenana Research Station, Abu Naama 250 km further south. For convenience the work can be presented under the following headings: work related to rotational effects; fallow hoeing effects; and residue incorporation effects.

2. ROTATION EFFECTS

The effects of different rotations on cotton yields were the earliest aspects of cotton cultivation studied in Sudan. These rotational experiments so far conducted are conveniently considered under three main categories, viz: rotations with unfertilized cotton, rotations with fertilized cotton and intensified crop rotations. In the earlier years, long staple cotton (*Gossypium barbadense*) and Dura (*Sorghum vulgare*) were the main crops, but after 1960, wheat and groundnuts assumed a great importance. Changes in the rotation experiments were introduced to take into account these other crops as well as the developments in the cropping pattern of the Gezira commercial scheme. In the earliest phase of the scheme when land was plentiful and cheap, and the amount of irrigation water being the major limiting factor, frequent fallows were the main feature in rotations. More recently, nitrogenous fertilization was practised and much more water became available for irrigation. The necessity for diversified cropping became much more obvious.

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[1] Agricultural Research Corporation, Wad Medani, Sudan

A wealth of information was accumulated by researchers in the field of soil science on the possible explanations of differential rotational effects. The metabolic behaviour of soil influenced by the energy-microbial activity relationships received appreciable attention. The practice of crop residue management is expected to influence the rotational effects. In the case of cotton, the stalks and debris are normally collected and burned for crop sanitation purposes. This is rather relaxed nowadays. The Dura stalks are mostly cut and carried away for feeding, leaving stumps. Wheat being harvested by combines leaves most trash. Groundnut haulms and *Dolichos lablab* fodder are mostly used for grazing *in situ*.

Jones (1957) investigated in some detail the relationship of soil organic nitrogen and nitrate N in various three course rotations viz CFF, DFC, DDC, LFC, and DLC (C = cotton, D = Dura sorghum, L = lubia (*Dolichos lablab*) and F = fallow). Results showed that soil nitrate figures are in distinct contrast to the figures for soil organic N which show marked dependence on rotation. This dependence is most clearly shown during the earlier sampling months of each season when it is assumed that the rain induces bacterial activity and consequent build-up of nitrates in soil. Rotation 4 (CLF) for each year studied showed a much higher soil nitrate content than the other rotations and the effect of this on ultimate cotton yields was very obvious (Table 1).

Table 1 COTTON YIELD AND SOIL NITRATES IN THE THREE COURSE ROTATION EXPERIMENT (MEAN OF SIX SEASONS)

	Rotation				
	FFC (1)	DFC (2)	DDC (3)	LFC (4)	DLC (5)
Long-term cotton yield (Kt/fed)	4.66	4.30	3.10	4.95	4.55
Long-term No_3 -N (ppm)	9.0	8.0	4.0	15.0	8.0

F = Fallow, D = Dura, *Sorghum vulgare*, C = Cotton, *Gossypium barbadense*,
L = Lubia, *Dolichos lablab*.

Similarly, Jones (1957) investigated the changes of soil organic nitrogen and nitrate nitrogen in what was called the Combined Rotation Experiment (Crowther and Cochran 1942) which is meant to give various intensities of cropping giving thirty phases of rotations. The same crops, cotton, Dura and lubia, were planted with intervening fallows. Detailed studies of the organic N and organic carbon further confirmed by Rai (1969) that rotations with more crop residues left behind contained much more organic N in the top-foot soil.

Jagnow (1964) in a detailed study of the influence of crops on Azotobacter in the irrigated Gezira soil reported on the top-foot changes in organic N and C and related Azotobacter content. It was evident that rotations with only cotton or fallows sustained much less counts of Azotobacter than the ones with Dura or lubia. He put forward his hypothesis that this can be easily understood if a rough estimate of the amount of plant material likely to be left behind in soil can be arrived at from crop yield records. The following average figures per year and rotation are based on the assumption that plant material equivalent to 50% of the root weight of cotton (being estimated proportional to their yield from plant measurements of Fadda 1962), 30% of the straw weight of sorghum, and 100% of the cut weight of Dolichos are returned to the soil. These figures he reported follow the same order as the average Azotobacter counts per rotation:

Rotation: Dura/lubia cotton	5.72	(1 465)
Dura/lubia - fallow - cotton	4.92	(1 122)
Dura/lubia - fallow - fallow -cotton	3.72	(977)
Continuous cotton	1.57	(428)
Cotton - fallow	1.44	(359)
Cotton - fallow - fallow	1.15	(291)
Cotton - fallow - fallow - fallow	1.27	(242)

(Azotobacter count in 1000/g soil and residues in kg/ha respectively).

The striking feature was that the Azotobacter count increased about fourfold if the bare fallow was replaced by sorghum and Dolichos in the rotation alternately. Further increasing the fallow length, decreased their numbers. This is clearly related to the estimated amounts of crop residues despite the fact that these are supplied very unevenly and only in the cropping seasons. The total count of micro-organisms ranging between 6-20 Million/g soil showed a similar pattern to Azotobacter except that under cotton after Dolichos their number was higher than under cotton after sorghum. The delayed effect of sorghum residues on Azotobacter counts can be expected since they have a wide C/N ratio and a very high content of soluble sugars, which was shown to be the cause of low yields in succeeding crops by locking up available N (Conrad 1927). When these decompose gradually in the next fallow season, sugars and decomposition products from cellulose become available to Azotobacter which, as reported by Anderson (1958), can be increased to high numbers (10^8) by sugars in field soils. The microbiological effects imposed by various intensities of irrigated cropping were given by Musa (1975).

The long-term Organic and Green Manuring Experiment (1944-1965) was designed to measure the direct and residual effects of these manures on cotton yield and residual effects on soil organic C and N (Taha 1965 and Rai 1969). Eight treatments were imposed on the rotation F-L-F-C-D-F-C (F = fallow, L = lubia, C = cotton, D = Dura.

In the first leg of the rotation half of the plots were under fallow and the other half under lubia thus giving rotations FFC DFC, and LFC DFC. The treatments can best be described by:

i. F-F and then from January fixed ration of lubia hay (1500 kg/ha) and sorghum straw (8000 kg/ha) fed to sheep folded C-D-F-C.

ii. F-F as in (i) plus cotton cake (1400 kg/ha) giving 132 kg^N/ha in ration C-D-F-C.

iii. F-F as in (i) plus cotton cake applied directly to soil in March and then ploughed in C-D-F-C.

iv. FFC D FC (Control)

v. L grazed by sheep folded in January F-C-D-F-C.

vi. L grazed by cattle (daily only) in January F-C-D-F-C.

vii. L ploughed in January F-C-D-F-C.

viii. L cut removed in January FC-D-FC.

The general picture of soil organic carbon at the termination of the experiment after 20 years of cropping and 3 applications of the manurial treatment was lowest in the control. The differences were marked in the top 15 cm but narrowed with depth. Among the non-lubia treatments the highest figure was obtained where, together with the folded sheep treatment, cotton cake was applied and ploughed in. In the lubia plots the highest value was obtained where the crop was ploughed in as a green manure. A similar trend was observed for organic N, the control treatment giving the lowest, followed by treatment where lubia was cut and removed, and highest where lubia was grazed by cattle. Intensive cropping reported by Taha (1967) showed marked superiority of rotations including lubia and cotton seed cake. Cotton yields as indicator of the superiority of the treatment is yet to be appraised.

Regarding the residual effects of legumes on cotton when they are cut and removed, experiments by Musa and Burhan (1974) showed that although the legumes, <u>Phaseolus</u> <u>trilobus</u>, <u>Clitoria</u> <u>ternatea</u>, green gram, etc. fixed appreciable quantities of atmospheric nitrogen, what is left in the soil by way of residues (roots and sloughing off nodular tissue) was very small and therefore a very marked response to fertilizer N was evident. Nonetheless, the base yield was much higher than in adjacent plots without legume or with sorghum or wheat preceding cotton. Evaluation of the contribution of roots, nodular tissue and remains of these legumes rarely exceeded 20 kg N/na (Musa and Burhan 1974).

Recently, intensified rotations (Burhan 1969) and the inclusion of such crops as wheat meant more energy containing residues. This is exemplified by the following:

a. Differential behaviour of rotations without wheat as compared with those with wheat in relation to cultural operations on cotton, i.e. where rotations contain wheat residues, application of water or prewatering as a practice on land to be under cotton appears to be more favoured than where a legume is included (wheat-F-cotton as against groundnut-F-Cotton).

b. Rotations with wheat and sorghum tended to support more active microbial population and higher soil respiration than rotations with fallows, a finding in line with earlier observations.

c. Response to higher doses of fertilizer nitrogen is indicated (Burhan 1971/1972).

The reflection of this in terms of agricultural practice is the popularity of prewatering as a practice (when water is available) in intensified rotations where wheat precedes cotton, directly or after an intervening fallow. In addition, it was recommended to increase the fertilizer dose from the normal level of 40 kg N/acre to 60 kg N/acre to cotton. This was specially recommended when two cereal crops preceded cotton in rotation. It was evident that where no fertilizer is given in these intensified rotations yield of cotton was low.

3. FALLOW HOEING AND EFFECT OF RESIDUES

Early in the forties, Crowther (1943) brought to the notice of researchers the benefits of fallow weeding in the irrigated Gezira cotton rotations. In practice wide rotations were used in which cotton was grown two out of every eight years and the land was left in natural grass fallow for at least four years. The beneficial effects of the unweeded fallow were amply demonstrated by Crowther and Cochran (1942). But eliminating the weeds from these fallows before ripening enhanced cotton yields in succeeding years much more than expected. This situation prevailed in an area with annual rainfall of 406 mm mainly in the three months of July, August and September. Weeds of the area are predominantly dicotyledons with minor grass species. Experiments were designed to study the long-term effects of the practice and to elucidate the possible mechanism of its action. Ferguson, Kordofani and Roberts (1960) reported the results of the effects of fallow hoeing on cotton yields in rotations in Sudan starting as early as 1941 using rotations which included the legume Dolichos and Dura sorghum beside cotton. It was evident that rotation with only fallows as fallow-fallow-cotton declined in yield in the latter years as opposed to rotations with either legumes or Dura and fallows. Explanations are tenable in organic carbon and nitrogen reserves. The importance of soil N as being available to the cotton in the form of nitrates has long been established and there is a close correlation between NO_3 content of the Gezira soil and crop yields (Jewitt 1956). Crowther (1948), also showed that hoeing fallows resulted in an increase in soil NO_3. It is however obvious that with yields of cotton dependent on NO_3 content of soil and the very small amount of soil nitrate present it is essential that the nitrate must be replenished. Replenishment results primarily from the nitrogen fixed by soil micro-organisms and in case of rotations containing legumes, also from that fixed by the leguminous crops followed in both cases by nitrificiation either direct or via crop or weed residues. Table 2, referring to rotation with weed fallows, shows that rotations containing legumes are the least critical as regard the organic nitrogen-nitrate complex.

Table 2 ORGANIC N AND NITRATE N IN THE THREE COURSE ROTATIONS
(Jones 1950-1952)

Rotation	Soil N in the cotton phase before planting	
	NO_3 - N ppm	Organic N ppm
FFC	9.0	307
DFC	8.3	308
DDC	5.8	312
LFC	10.9	320
DLC	8.5	329

In the case of rotations with cotton and fallow (hoed), cotton has all the NO_3 at its disposal but less N is tied up in the soil and the reserve for nitrification is lower. Because of the strict crop hygiene practised in the Gezira, it is possible that in intensive weeding in such a rotation the loss of even the small reserve of N and organic matter may become cumulative. Continued hoeing of the fallows under the circumstances described would thus ultimately result in extreme depletion of organic matter. From data available in the Gezira, there is no evidence that such extreme depletion is taking place.

In 1947 an elaborate experiment with only cotton and two fallows in various combinations of hoeing were compared (The Permanent Fallow Hoeing Experiment, 1947). This was split for N in the mid-sixties to give indications of the effect of fallow hoeing on the supply of N to the cotton crop.

The trend of cotton yields since 1947 has shown variations which are clearly influenced by both seasonal and treatment effects. Invariably, hoeing the fallow immediately before the cotton phase increased yields. Hoeing the two fallows increased the yield appreciably. The change of response over the past 28 seasons is analysed. The splitting of the experiment for N application since 1966 indicated appreciable response to N application, but invariably the response was highest where no hoeing was practised. This reflects a state of lower availability of nitrogen in unhoed fallows.

Explanations of the beneficial effects of fallow hoeing as a practice in irrigated Gezira are still a matter of concern to scientists. Crowther (1943) postulated that a loss of N might be produced through temporary immobilization of N in mature weed residues accentuating the deficiency already widespread in Gezira soils. After the weeds have ripened and seeded unchecked, there remains an abundance of straw-like material which in the dried-out soil fails to decompose till the early rains, i.e. a month or two before the start of the cotton season. Thus decomposition may be incomplete when the cotton plants begin to absorb N and the amount of N absorbed may be less in consequence. This was not offset later as evidenced by crop N uptake figures. Furthermore, the residual effects of the treatments as measured by the yield of the succeeding Dura crop did not reflect a state of temporary immobilization (Crowther 1943). Loss of N via soil is not likely. Any nitrogen lost to the cotton must therefore have previously been absorbed by the weeds. Exactly how this absorption by the weeds could lead to loss is not at present understood. Grazing of the weeds was not responsible since animals were kept out of the experiment. However, termites provide a possible explanation. These play a role in tropical soils similar to that of earth worms in temperate soils in that they move organic matter from surface down to subsoil. Termites are numerous and general in Gezira soils evidenced by casts, fungus gardens and deep nitrates in subsoil (Snow and Greene 1935). On this explanation N would be lost to the surface soil unless seasonal or agricultural conditions encourage exceptionally deep rooting of the cotton and the consequent tapping of these reserves.

Loss of N by decomposing residues by reason of alkalinity of the Gezira soil, if it exists at all, should apply equally to both hoed and unhoed treatments.

A gain in N when immature weeds are hoed could be suggested. Limited evidence available indicates that immediately after weeding the fallow in September, hoed fallows contained twice the number of Azotobacter as unhoed fallows in the first foot of soil but differences were not evident two weeks before planting the cotton crop (Musa 1976).

Organic C and organic N in the Permanent Fallow Hoeing Experiment show some differences in the top-foot layer between hoed and unhoed treatments. More Nitrate N however was mineralized in incubated first food hoed treatments. It seems logical to suggest that a great deal may be gained by fractionation of soil organic N in such an experiment. Soil respiration, however indicated a higher level of activity in unhoed treatments in mid July or just two weeks before planting the cotton crop as shown in Table 3.

Table 3 ORGANIC CARBON, ORGANIC NITROGEN, AZOTOBACTER COUNTS AND SOIL RESPIRATION IN THE PERMANENT FALLOW HOEING EXPERIMENT

Fallow treatment	Org. C %	Org. N ppm N	NO_3-N Mineral-ized	Azotob. x 1000/ g soil	Soil Resp. mg CO_2/100 g soil in 2 wks
Not hoed (F_1)* - Not hoed (F_2)	0.332	308	14	1.65	8.6
Not hoed (F_1) - Hoed (F_2)	0.326	292	18	1.72	9.0
Hoed (F_1) - Not hoed (F_2)	0.328	287	17	1.41	8.4
Hoed (F_1) - Hoed (F_2)	0.316	285	22	1.84	7.8
S.E. ±	0.011	8.5	4	0.24	-

* F_1 = First fallow; F_2 = Second fallow

4. RESIDUE INCORPORATION EFFECTS

In an attempt to explain the effects of decomposing residues on the extent and magnitude of the immobilization of mineral N, a wide variety of crop residues usually encountered was analysed for its carbon and nitrogen content and the status of nitrates determined in soil samples incubated for about 9 months. The residues were incorporated at a rate equivalent to 2 tons/acre field application. Table 4 gives the results of C/N ratio of residues and length of the mitrate immobilization phase.

Table 4 DURATION OF MINERAL N IMMOBILIZATION WITH VARIOUS CROP RESIDUES
(after Musa 1969)

Crop residue	C/N ratio	Duration of N immobilization weeks
Dura leaf (Mature)	95	28
Dura stem "	120	35 +
Dura root "	126	35 +
Cotton stem "	86	35 +
Cotton root "	76	35 +
Groundnut leaf	20	3
Groundnut stem	58	10
Groundnut root	63	10
Lubia nodules	18	1
Groundnut nodules	14	3
Brachiaria weeds (whole plants)	122	35 +

The result pertains to residues incubated with soil in pots maintained at 30% moisture and replenished at weekly intervals. However, increasing the soil moisture to 50% (about field capacity) resulted in a much faster breakdown of all residues and in copious release of nitrate (Musa 1969). Microbiological investigations confirmed that in the low moisture decomposition both fungi and actinomycetes predominated whereas at 50% moisture the bacterial population was much more active. An overall balance of nitrogen may thus be needed to assess the trends of the nitrogen fractions with the different crop residues. This work is currently under consideration.

Jagnow (1961) studied the agronomic effects of different composts applied at a field rate of 10 tons/acre on succeeding cotton. Results showed that three preparations of composts made of cotton stalks and activating layers of soil, fertilizer, or manure had a positive effect on cotton yield and Azotobacter number in soil 9 months from application time.

Rai (1965) investigated the sorghum straw disposal in the central rainlands of the Sudan where Dura is grown on a very extensive scale and enormous amounts of straw being produced. However, due to the high clay content of the soil it cannot be disced in the late dry season when the soil moisture is at its low ebb. Sorghum straw obtained from early harvested fields could well be disced in immediately after harvest which is only a small fraction. Most straw disposal by discing has to wait softening of the ground during the following rains. However the undecomposed straw disced at this time of the year interferes with the usual agricultural operations like planting and weeding.

Currently, the practice of straw disposal in the central rainland areas is to burn it during the dry season, a practice by which great amounts of organic matter and nutrients, mainly N, are lost to soil. In a comparative study where 1) burning, 2) discing in, 3) removal, and 4) mulching were compared using the yield of sesame as the indicator crop, removal of residues was superior in all cases and incorporation and discing most inferior. Addition of 20 kg N/acre resulted in nearly equal yield in most of these treatments. Explanation is sought in the slow decomposability of sorghum straw residues and the immobilization of nitrate N by residues of a wide C/N ratio. The author expressed his concern regarding the N losses from burnt residues and called for judicious alternative use. It is thought that the use of fertilizer N, where economics allow, can be recommended. Alternatively long fallows with incorporation or short fallowing with green manures were advocated as a means of ensuring a good supply of available N to succeeding non-legumes. The use of cash leguminous grain or fodder crops in rotation after sorghum is also under consideration. At Abu Naama, now the centre for both rainland and irrigated cropping practices, due consideration should be given to the long-term effects of the different methods of sorghum straw disposal on soil constituents and characteristics.

At the Gezira Research Station, the use of more intensified rotations and the integration of animals in the system called for experimentation with various legumes both as feed and as green manures. In the old Organic and Green Manuring Experiments, already discussed, a whole season elapses before another crop is planted. This is no longer suitable for very intensified rotations.

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Paper 13

EFFECTS OF STRAW APPLICATION ON THE FERTILIZER NEEDS OF A SORGHUM/COTTON ROTATION IN NORTH CAMEROON

J. Gigou [1]

1. INTRODUCTION

Economy in the use of mineral fertilizers and the study of cultivation systems, enabling an increase in production with only a modest contribution from fertilizers, have always been important goals for agronomists working in the dry regions of tropical Africa.

Considerable savings in fertilizers can be realized by using the mineral elements found in crop residues. In tropical Africa, where the use of manure is very limited, the burying of straw seems to be one of the most promising methods. However, it also raises many problems. Hence, this study which was started in 1973.

The work was carried out in north Cameroon in an area stretching from Chad to Nigeria and up to Lake Chad. The principal towns are Garoua and Maroua. The trials were carried out at Sanguéré, Soucoundou and Maroua.

Garoua receives about 1 000 mm of rain from May to October. Maroua a little less.

The soils have been described and mapped by ORSTOM as follows:

- in Sanguéré as a leached tropical soil deficient in N and P derived from sandstone;
- in Soucoundou, as a "red tropical soil" derived from gneiss. It is not very deep, is highly erodible and is deficient in N and P;
- in Maroua, as a "young, alluvial soil", variable, at times sandy, at times clayey. It is on the whole very fertile, but is deficient in nitrogen.

2. ROTATION

The principal crops of this region are sorghum, cotton and peanuts. Extension work with maize and rainfed rice is carried out. For these trials the rotation is only cotton-sorghum.

3. MINERAL UPTAKE

The quantities of mineral elements taken up in sorghum cultivation were studied in Maroua in 1975, using the IRAT 55 variety. Sowing took place on 26 June 1975 and the production was 4.5 t/ha of seeds.

Figure 1 shows the increase in the weight of dry matter in the aerial parts of the plant. Figure 2 shows the accumulated qualities of the principal elements in the aerial parts of the plant expressed in percentage at the time of harvest. It is observed that potassium is accumulated the fastest, followed by nitrogen, magnesium, calcium, phosphorus and, finally by sulphur.

At harvest time, it is possible to calculate the uptake by the straw heads and seeds as shown in the following table. Straw extracts the greatest part of the potassium, 1/3 of the nitrogen and 1/3 of the phosphorus and almost all of the calcium.

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[1] IRAF Nord, Maroua, Cameroon

kg/ha for 4.5 t of seeds

	N	P_2O_5	K_2O	CaO	MgO	S
aerial parts	93	52	136	36.5	32	17
straw	32	16	110	33	20	9
heads	61	36	26	3.5	12	8
seeds	60	35	22	2.3	11	7.5

kg/t of seeds

	N	P_2O_5	K_2O	CaO	MgO	S
aerial parts	20	11.5	30	8	7	3.7
straw	7	3.5	24	7.2	4.4	2
heads	13	8	6	0.8	2.6	1.7
seeds	13	8	5	0.5	2.4	1.6

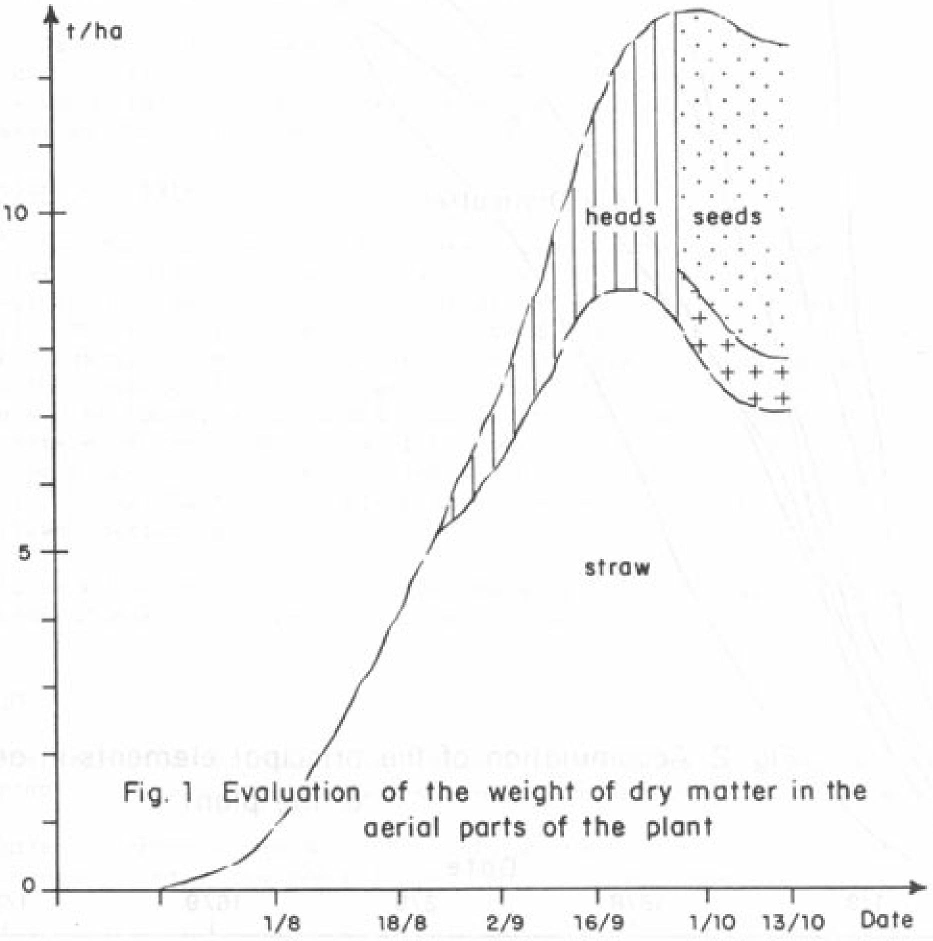

Fig. 1 Evaluation of the weight of dry matter in the aerial parts of the plant

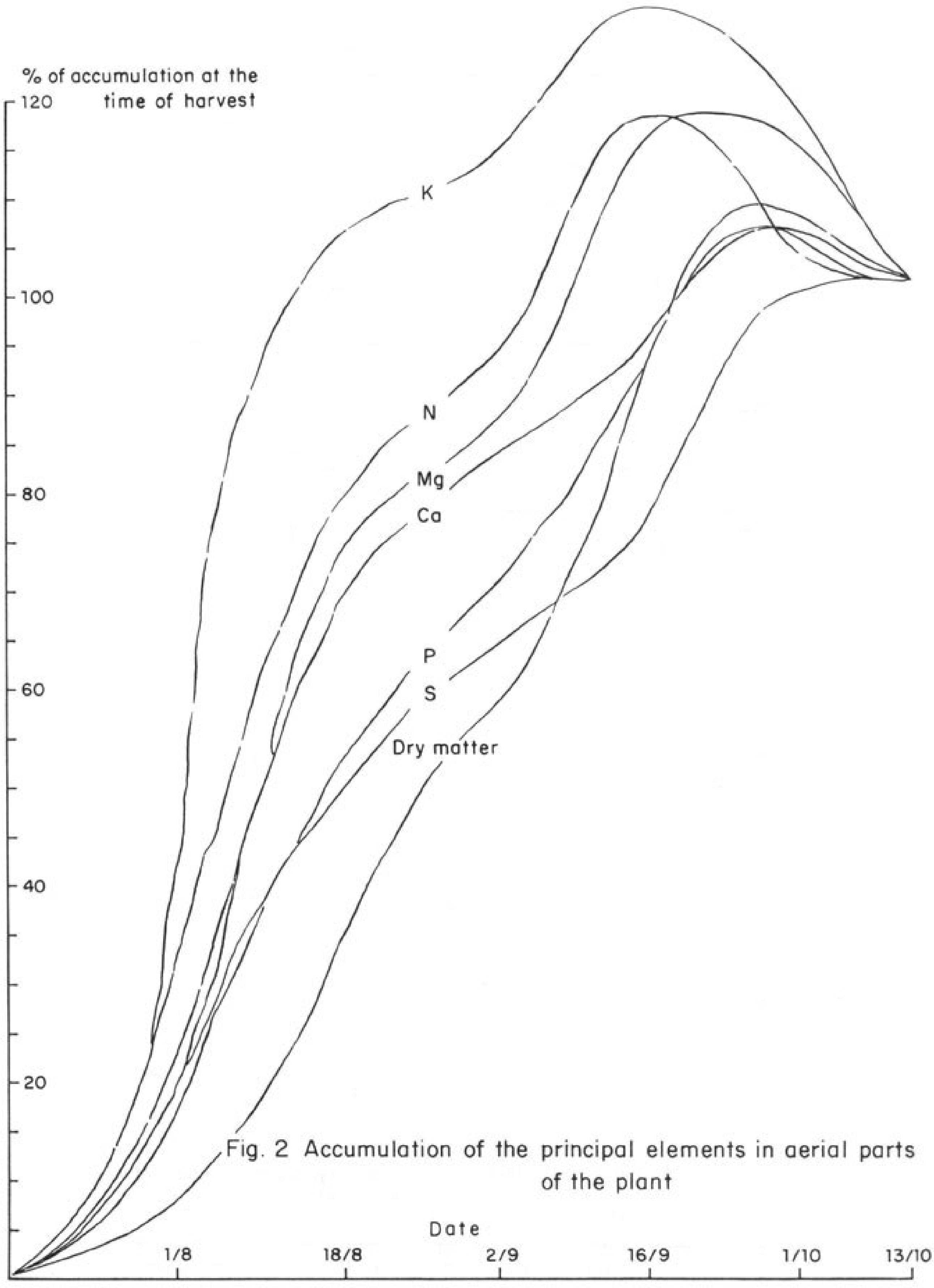

Fig. 2 Accumulation of the principal elements in aerial parts of the plant

In our example, if the straw is ploughed back into the soil, applying fertilizer at the rate of 60 kg/ha N - 40 P_2O_5 - 30 K_2O is sufficient to compensate for the extractions. If the straw is not returned to the soil, a greater quantity of fertilizer is needed to prevent degradation of the soil.

4. EFFECT OF STRAW APPLICATION ON THE AVAILABILITY OF NITROGEN TO THE PLANT

The incorporation of straw in the soil raises problems. Its effects are fairly well known in temperate countries where it has been demonstrated that after burning the straw, there is a rapid organization of a great quantity of mineral nitrogen which is slowly remineralized over the following months and years. Consequently, crops planted immediately after the application of straw can suffer from lack of nitrogen and produce less, if this effect of straw is not compensated for by adding nitrogenous fertilizers. In tropical countries, the results are rather confusing and not as simple because both depressed yields and increases in production have been reported at various levels of nitrogenous fertilization. This study, therefore, hopes to provide information under the ecological conditions that prevail in Northern Cameroon.

4.1 The Sanguéré Trials

These trials consist of applications of nitrogen (0-50-100 kg/ha) and 3 applications of straw (0-5-10 t/ha) in a factorial combination. They began in 1973 with the cotton-sorghum rotation. In 1975, cotton plants of the BJA 592 variety were cultivated. Sorghum straw was incorporated in May using ox-drawn ploughs. The whole trial received adequate P-K-S-B fertilizer.

In Figure 3, it is seen that, in Sanguéré, without nitrogen, 10 t/ha of straw decreases the cotton yield by 350 kg/ha, but when nitrogen is applied, the differences between various rates of straw are less and no longer significant. It seems that the curves meet at 70-80 kg/ha of nitrogen.

4.2 The Soucoundou Trials

In Soucoundou, the plots have been given increasing doses of nitrogen since 1970, under the cotton-sorghum rotation. In 1975 the plots were sub-divided into two sub-plots, one receiving 10 t/ha of straw and the other receiving no straw (control). The results are shown in Figure 4 and they are very similar to those in Sanguéré. Again, there is a drop in the cotton yield of 350 kg/ha for 10 t/ha of straw in the absence of the nitrogen application. When nitrogen is added, the differences are no longer significant, but if the response curves are followed, they are seen to intersect around 60 kg/ha of nitrogen. The control plot has received no fertilizers since 1970, but a sub-plot which had straw applied gave the greatest yield; it is possible that the straw contained mineral elements (P and K probably?) which allowed better growth.

It is noted then, that in impoverished soils, the favourable effect of the straw which adds mineral elements is much greater.

5. CONCLUSION

The extraction of mineral elements from the straw and the crop residues plays an important role, and rational agriculture must provide for their recycling.

Under Northern Cameroon conditions, where the use of manure is very limited, the incorporation of straw seems to be one of the best methods of recycling minerals.

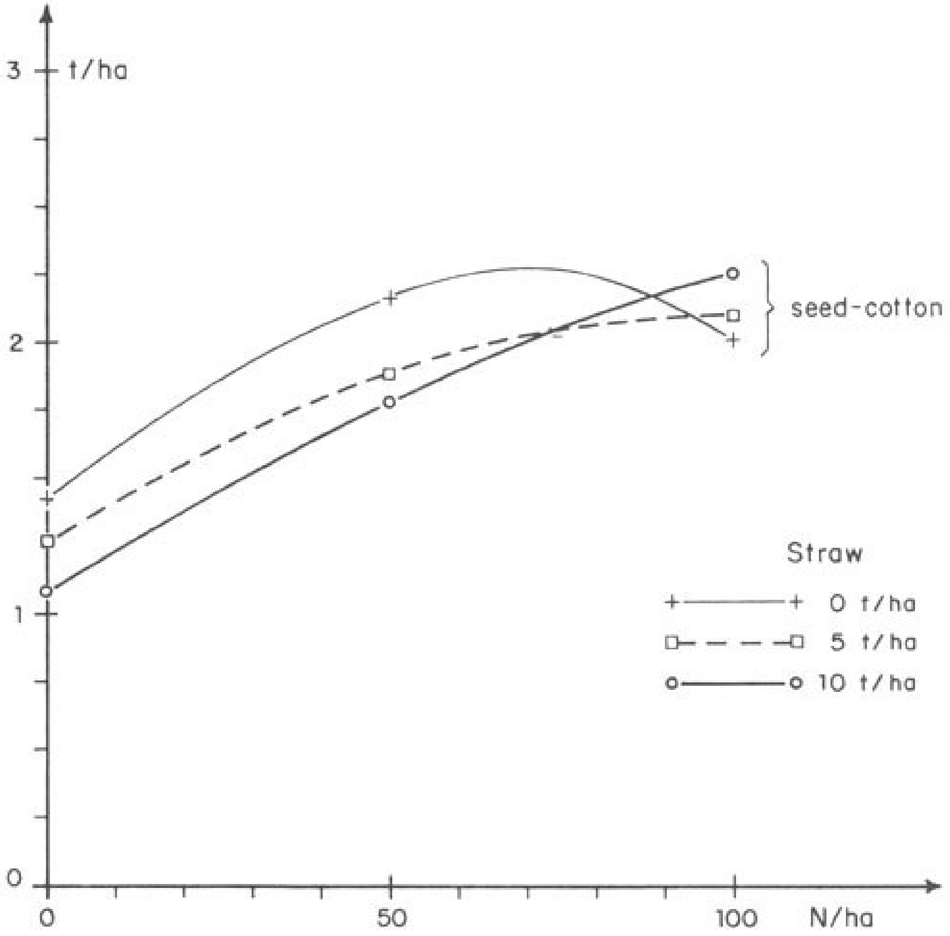

Fig. 3 Results in Sanguéré

If the results are confirmed by further experiments, it will be advisable to recommend the incorporation of straw along with the fertilizer already in use. In fact, this fertilizer adds 66 kg/ha of N, so there will be practically no depressed yield effect of the buried straw by the mobilization of the mineral nitrogen. This practice will lessen the mineral uptake, especially that of potassium.

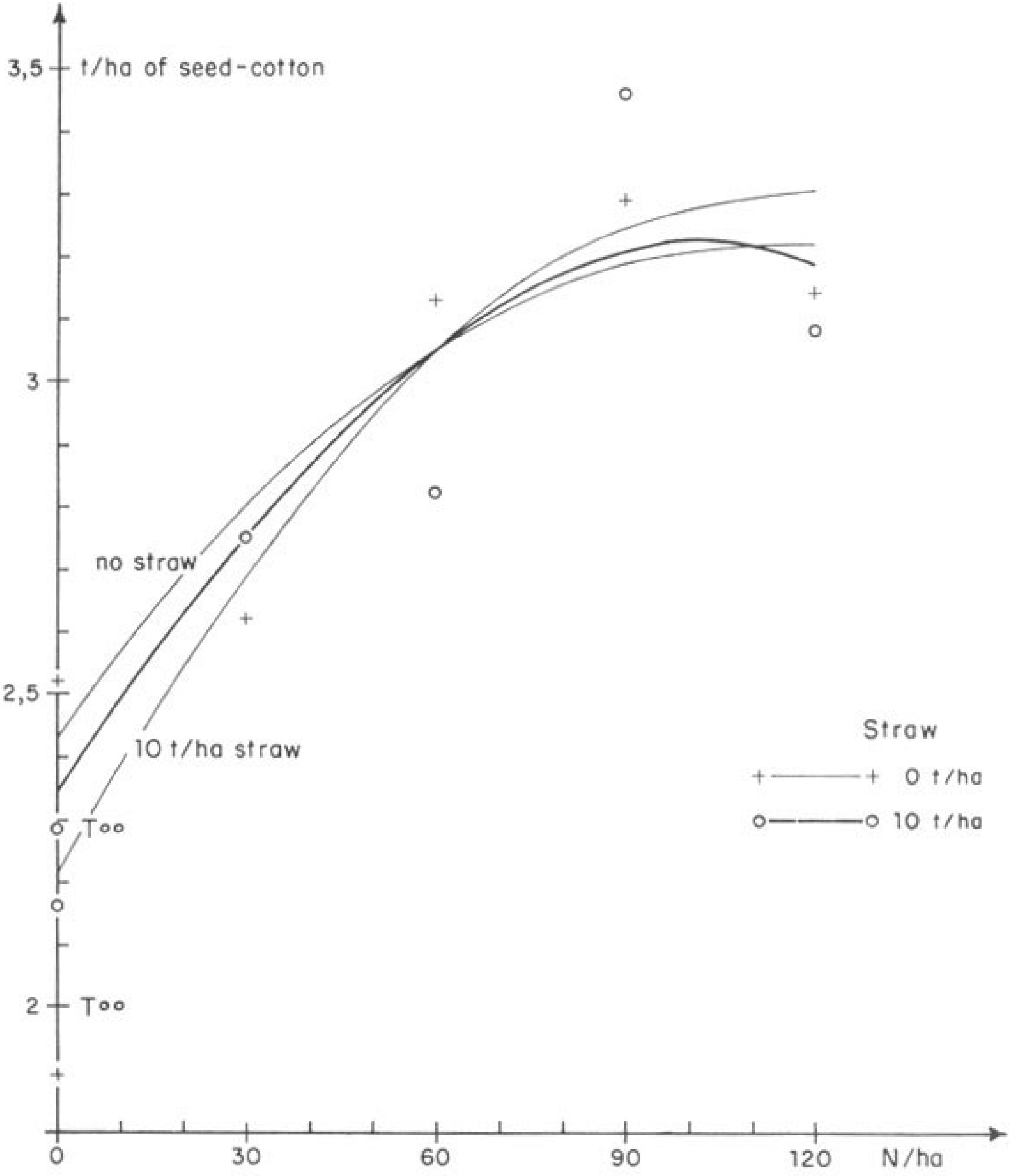

Fig. 4 Results in Soucoundou

Paper 14

INTERACTION BETWEEN FARMYARD MANURE AND NPK FERTILIZERS IN SAVANNA SOILS

Uzo Mokwunye 1/

1. INTRODUCTION

In the West African sub-region, by far the greater part of the area between the Sahara in the North and the Atlantic in the South is covered by savanna - a sub-humid to semi-arid tropical woodland. Because of its sheer size, the savanna is not uniform. Climatic differences affect the nature of the vegetation, the types of crops that could be grown as well as the potential yield of the various crops. However, some common features can be recognized in savanna soils. Nutrient contents range from very poor to poor. In addition to a low clay content, Jones (1976) found that the mean carbon content of 605 well-drained savanna sites was 0.68%. The net results are soils which are very poorly buffered and have very low cation exchange capacities.

Although crops can be grown in the absence of organic matter, it is common experience that it is much cheaper and easier to grow crops in soils which contain organic matter. The influence of organic matter as a source of plant nutrients, as a stabilizer of soil structure and as an important contributor to the cation exchange capacity of savanna soils has been amply demonstrated (Nye 1950; 1951; Nye and Greenland 1960; Fauck 1963; Morel and Quantin 1964; Martin 1970; Jones 1973; Jones and Wild 1976).

It is not surprising, therefore, to find that all through the sub-region, the traditional farmer has always appreciated the importance of organic manures. Domestic wastes and animal droppings, as well as ashes are usually collected and applied to the more frequently cropped "garden" land around the homestead.

2. GENERAL SURVEY

Hemingway (1961) analysed fifty samples of farmyard manure and found that the mean nutrient composition in the dry matter was:

N	1.73%
K	1.29%
Ca	0.74%
Mg	0.34%
P	0.24%
Mn	182 ppm
Cu	19.8 ppm
Mo	2.32 ppm
Co	1.66 ppm

Based on this analysis, he calculated that 10 tons of 20% dry matter farmyard manure would supply as much plant food as 176 kg ammonium sulphate, 61 kg single superphosphate and 51 kg muriate of potash.

Across French West Africa, analysis of nutrient composition of farmyard manure has revealed the following (Prevot and Martin in Upper Volta, 1964; Delbosc in Senegal 1965; Pieri in Mali, 1971):

N	0.48 to 1.95%
P	0.06 to 0.57%
K	0.39 to 2.62%

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With this background it is easy to understand why much of the early work with farmyard manure in the savanna had been geared towards obtaining direct response to its application in the absence of inorganic fertilizers.

In 1952, Nye reported that there was a negative interaction between farmyard manure and superphosphate at phosphate deficient sites in Northern Ghana where the effects of phosphate were high. This would indicate that the main value of manure was to supply phosphorus.

In a long-term trial in Tanzania, Le Mare (1972) found that farmyard manure or compost or ammonium sulphate improved and maintained cotton yields for six years but a mixture of the farmyard manure and both ammonium sulphate and superphosphate was needed to maintain cotton yields for nine years.

Table 1 YIELD OF COTTON UNDER CONTINUOUS CULTIVATION AT BANBARI, CENTRAL AFRICAN REPUBLIC (Richard 1967)

Treatment	Mean	Seed cotton yield	(Kg/ha)
	1st 3 yrs 1956–58	Last 3 yrs 1964–66	All yrs 1956–1966
Control	1 294	1 146	1 178
Manure at 20 t/ha/yr	2 068	2 022	1 909
NPK fertilizer*	1 623	1 919	1 665
Manure + fertilizer	2 079	2 437	2 024

* Fertilizer rates varied from year to year but total application over 11 years was approximately 690 kg N, 340 kg P and 100 kg K per hectare.

Richard's work (1967) in the Central African Republic (Table 1) shows that yields were maintained over an eleven year period by the application of 20 t/ha of farmyard manure. Over the same period, yields were increased gradually when NPK fertilizers were applied. However, highest yields occurred when manure and NPK fertilizers were applied together.

Roche (1970) showed that yields of rice increased linearly with increasing rates of nitrogen fertilizer in the absence of farmyard manure up to a maximum of 60 q/ha at the rate of 200 kg N/ha. However, at 160 and 200 kg N/ha, addition of farmyard manure or compost increased yields by as much as 886 kg/ha and 965 kg/ha respectively. With this combination maximum yield rose to 69 q/ha. Statistical analysis showed that the Nx F Y M interaction was highly significant. Ganry et al (1974) found that the addition of either composted millet straw or farmyard manure produced significantly increased yield (+ 600 kg/ha) in combination with 30 kg N/ha. In the absence of the organic materials, an additional 60 kg N/ha would have been required to produce the same yield.

Table 2 YIELD OF COTTON, SORGHUM AND GROUNDNUTS IN A 7-YEAR ROTATION AT M'PESOBA, MALI (Poulain 1976)

Fertilization Pattern	Cotton	Sorghum kg/ha	Groundnuts
No farmyard manure	570	490	920
Annual fertilizer application	1 190	1 350	1 480
Farmyard manure alone	1 270	970	1 130
Fertilizer + F Y M	1 650	1 530	1 610

After a 7-year rotation of cotton-sorghum-groundnuts and fallow at M'Pesoba in Mali, Poulain (1976) observed that yields of cotton, sorghum and groundnuts were increased by 1 080, 1 040 and 690 kg/ha respectively when NPK fertilizer was combined with farmyard manure.

NPK fertilizer alone resulted in increases of 620, 860 and 560 kg/ha of cotton, sorghum and groundnuts respectively while farmyard manure alone resulted in increases of 700, 480 and 210 kg/ha for cotton, sorghum and groundnuts respectively (Table 2).

3. THE NIGERIAN EXPERIENCE

Early investigational work on soil fertility in the Nigerian savannas was mainly confined to the response of crops to farmyard manure (Hartley and Greenwood 1933). The early success achieved with the addition of as little as 2 t/ha of farmyard manure led to the erroneous conclusion that farmyard manure owed much of its effectiveness to the presence of nitrate-nitrogen in addition to a "specific" effect which could not be simulated by chemical fertilizers. The 1933 data presented by Hartley (1937) showed that NPK applied at the rate of 179 kg/ha $NaNO_3$ (160 lb $NaNO_3$/ac) 72 kg/ha superphosphate (64 lb superphosphate/ac) and 81 kg/ha KCl (72 lb KCl/ac) was as effective as 2 t/ac of farmyard manure. The farmyard manure had a composition of 1.09% N, 0.3% P_2O_5 and 1.58% K_2O. A mixture of 2.2 t/ha (2 t/ac) of the farmyard manure and NPK at the above doses was not significantly better than the 2.2 t/ha (2 t/ac) of FYM alone (Table 3).

Table 3 YIELD OF SEED COTTON (1933) AND GUINEA CORN (1934) (Hartley 1937)

Treatment	Seed cotton kg/ha	Seed cotton (lb/ac)	Guinea corn kg/ha	Guinea corn (lb/ac)
0	189	(169)	594	(530)
1 t FYM/ac	278	(248)	815	(727)
NPK	382	(341)	1 162	(1 037)
2 t FYM/ac	390	(348)	1 162	(1 037)
FYM + NPK	407	(363)	-	
2 NPK	479	(427)	1 633	(1 457)
Difference needed for significance	87	(78)	259	(231)

The results of the 1935 Guinea corn trial can be conveniently grouped into four categories (Table 4).

Table 4 GUINEA CORN YIELDS IN 1935

	Treatment	Grain yield		Stems and Leaves	
		kg/ha (lb/ac)			
(a) No farmyard manure but with mineral fertilizers excluding phosphorus	O	751	(670)	5 616	(5 010)
	N	712	(635)	5 616	(5 010)
	K	895	(798)	6 345	(5 660)
	NK	661	(590)	5 370	(4 790)
(b) Farmyard manure and combination of FYM and mineral fertilizers excluding P	FYM	1 383	(1 234)	11 154	(9 950)
	FYM + N	1 332	(1 188)	10 896	(9 720)
	FYM + K	1 312	(1 170)	11 322	(10 100)
	FYM + N + K	1 301	(1 161)	11 210	(10 000)
(c) Mineral fertilizers including P	PK	1 343	(1 198)	11 031	(9 840)
	P	1 502	(1 340)	11 714	(10 450)
	NP	1 525	(1 360)	13 743	(12 260)
	NPK	1 565	(1 396)	13 385	(11 940)
(d) A combination of FYM and mineral fertilizers including P	FYM + P	1 993	(1 778)	16 434	(14 660)
	FYM + P + K	1 939	(1 730)	16 142	(14 400)
	FYM + N + P	2 063	(1 840)	19 281	(17 200)
	FYM + N + P + K	2 124	(1 895)	19 169	(17 100)
	LSD	212	(189)	17 488	(1 560)

It could be seen that yields in (a) are significantly inferior to those in both (b) and (c) and all the latter are worse than (d). It is important to note here that the yields in (b) are not significantly different from those in (c) which goes to show the important role played by farmyard manure in the enrichment of soil phosphorus.

In a long term trial at Samaru on plots previously cropped for twenty years with cotton, sorghum and groundnuts without mineral fertilizers but with four rates of farmyard manure applied annually, Abdullahi (1971) showed that when the plots were split and maize was sown at three levels of NPK fertilizers, yields were greatly increased by both the fertilizers and the cumulative effects of the twenty annual applications of FYM. Of equal importance was the observation that at the highest rates of fertilizer and manure, maize yields were double what they were at the highest rates of the mineral fertilizer alone. The highest rate of fertilizer produced little over 2 000 kg grain/ha on unmanured plots, a very poor response by local standards (see Table 5).

Table 5 MAIZE YIELDS (kg/ha) AS AFFECTED BY FERTILIZER AND PREVIOUS MANURING ON A 20 YEAR OLD FIELD AT SAMARU, NIGERIA

Fertilizer (kg/ha)			Previous	Long-term (Tons/FYM/ha/ac)	Treatment	(Tons/FYM/ha/ac)
N	P	K	0	2.5	7.5	12.5
0	0	0	33	584	2 543	3 145
134	28	56	1 016	2 316	3 775	3 821
268	56	112	2 065	3 311	4 108	4 247

The most sustained effort at Samaru to study the interaction of farmyard manure and NPK fertilizers is the trial set up in 1950 to ascertain the response to and relative long term effect of continuous annual application of various levels of NPK fertilizers and FYM alone and in all combinations to a local crop. The experiment was initially set up at Kano, Samaru, and Mokwa. The trials at Samaru and Kano are in their 27th year and the results continue to provide very useful information on the management of savanna soils. The rates of FYM have remained constant at 0, 2.5 and 5 t/ha, and Table 6 (taken from the 1965 data) is typical of the results obtained over the years.

Table 6 INTERACTION OF NPK AND FYM ON YIELD OF COTTON SEED AT SAMARU (1965) kg/ha

(a)*D x N				(b)*D x P				(c)*D x K			
	D_0	D_1	D_2		D_0	D_1	D_2		D_0	D_1	D_2
N_0	244	471	690	P_0	116	531	760	K_0	378	668	746
N_1	396	674	812	P_1	446	741	841	K_1	387	636	885
N_2	433	884	983	P_2	510	757	884	K_2	308	725	853
SE = 57				SE = 57				SE = 57			

5% significant difference = 162

*D = Dung or Farmyard manure

Although various modifications have been made over the years to improve the experiment, there had always been a marked response by all crops to N, P and farmyard manure. Before 1972, the rates of N, P, and K were 0, 10, and 22 kg N/ha; 0, 4.5 and 9.0 kg P/ha and 0, 14 and 28 kg K/ha respectively. These levels were very low and the early reports (Obi 1959) showed better results from farmyard manure than from inorganic fertilizers. Since 1972, the N, P and K rates have been increased to 0, 67 and 134 kg N/ha; 0, 29 and 59 kg P/ha and 0, 46 and 93 kg K/ha respectively.

Table 7 INTERACTION EFFECT OF FARMYARD MANURE (D) AND P ON THE AVERAGE YIELD OF MAIZE (kg/ha) - 1973 (Mokwunye 1977)

	P_0	P_1	P_2
D_0	660	3 350	3 210
D_1	2 160	4 200	4 060
D_2	3 820	4 640	4 270

SE ± (197)

Table 7 shows that the combination of 5 t /ha of farmyard manure and 29 kg P/ha gave maximum maize yield in 1973. The significance of farmyard manure as a source of P is thus obvious. But farmyard manure is also an important source of N as is evident from the data in Table 8.

Table 8 INTERACTION EFFECT OF FARMYARD MANURE (D) AND NITROGEN ON THE YIELD OF MAIZE (kg/ha) - 1973

	N_0	N_1	N_2
D_0	330	2 660	3 900
D_1	920	3 750	4 500
D_2	2 000	3 730	5 180

Soil samples were taken from all the plots in 1967 and 1973 so that the build-up of residual phosphorus could be monitored. The table that follows reveals some of the findings.

Table 9 INTERACTION EFFECTS OF FARMYARD MANURE (D) AND P ON THE RESIDUAL P (kg/ha) IN TOPSOIL (0–15 cm)

(a) Resin-extractable P

1967

	P_0	P_1	P_2	Mean
D_0	2.0	8.0	13.1	7.7
D_1	2.6	7.4	18.2	9.4
D_2	5.7	10.2	18.2	11.4
Mean	3.4	8.5	16.5	

1973

	P_0	P_1	P_2	Mean
D_0	2.7	21.8	69.6	31.4
D_1	4.5	32.0	63.5	33.3
D_2	8.4	44.8	95.1	49.4
Mean	5.2	32.9	76.1	

(b) Water-extractable P

1967

	P_0	P_1	P_2	Mean
D_0	0.2	0.7	1.6	0.8
D_1	0.3	1.0	2.9	1.4
D_2	1.0	1.5	2.9	1.8
Mean	0.5	1.1	2.5	

1973

	P_0	P_1	P_2	Mean
D_0	0.2	4.2	28.7	11.0
D_1	0.9	10.3	27.4	12.9
D_2	2.4	17.5	37.5	19.1
Mean	1.2	10.7	31.2	

Table 9 shows that a substantial amount of "available" phosphorus had accumulated in the plots between 1967 and 1973. Analysis of variance on the results showed that farmyard manure, N and P all had a significant effect on the extractable residual phosphorus. A closer look at Table 9(a) shows that 5 t /ha of farmyard manure increased the resin-extractable P by 5.7 kg P/ha in the P_0 level and 25.5 kg P/ha in the P_2 level in 1973 showing a strong positive interaction between manure and phosphorus fertilizer. The increase in water-extractable P (Table 9(b) was from 2.2 kg P/ha to 8.8 kg P/ha. It should also be noted that when manure is the only source of P fertilizer are present, the extractable P build-up is usually much greater.

4. CONCLUSION

Farmyard manure has been widely tested in the savanna. Its principal benefit seems to be in its capacity to supply both N and P. The latter is of immense importance in the drier parts of the savanna where levels of available phosphorus are extremely low. It should be borne in mind that farmyard manure is scarce and only fundamental changes in the present system of farming in the savanna can change the situation. Evidence presented in this paper shows that use of both farmyard manure and inorganic fertilizers not only results in good yields but also reduces the absolute quantities of the latter needed for optimum crop production.

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Paper 15

RESULTS OF EXPERIMENTS ON LEGUME INOCULATION AND NITROGEN FIXATION IN ZAMBIA

M.N. Zayed [1]

1. INTRODUCTION

The need to increase production of crops with a high protein content has become an urgent necessity because of the striking increase in world population. As a consequence of the 1973 energy crisis, the prices of "industrialized" nitrogen fertilizers have skyrocketed and have therefore affected their utilization in developing countries. This has promoted a search for other nitrogen sources among which the most widely used and known system is that of symbiotically fixed nitrogen, by various species of Rhizobium in leguminous plants.

In this regard, a programme of work on symbiotic nitrogen fixation in grain and forage legumes was initiated in Zambia in 1973. More emphasis has been devoted to soybean (Glycine max.L) because of the growing enthusiasm for soybean farming in the country.

The programme included:

i. selection of efficient rhizobia in greenhouse experiments;

ii. assessment of effect of inoculant and nitrogen on yield of soybean;

iii. evaluation of the residual effect of nitrogen fixation;

iv. search for an economic medium for mass-scale production of Rhizobium culture for inoculant production;

v. interaction of fungicides, insecticides and herbicides with rhizobial activity.

2. EXPERIMENTS

2.1 Experiment I: Selection of Efficient Strains of Rhizobium Japonicum

In a sterile sand culture, soybean seeds of the Bossier variety were inoculated with each of six strains of rhizobia. Five seeds were planted in each pot, replicated four times and the plants thinned to three after germination. The pots were irrigated regularly with modified Piper (1942) N-deficient nutrient solution. Six weeks after germination the plants were removed gently and the nodules on each plant were counted, dried and weighed. Protein was determined in the plants and the weight of dried plants was recorded.

Table 1 indicates that strains 67 and 46 were the most efficient ones as evidenced by the increases of 33.7 and 28.6% respectively in weight of protein in the inoculated plants over the uninoculated ones.

2.2 Experiment II: Assessment of Effect of Inoculant and Nitrogen on Yield of Soybean

The response of soybean grain yield to inoculant and to nitrogen fertilization was investigated at the regional research stations, to cover as wide a range as possible of different environments in Zambia.

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Table 1

NODULATION AND NITROGEN FIXATION EFFICIENCY OF SOME STRAINS OF RHIZOBIA IN BOSSIER SOYBEAN

Mean of 3 plants replicated 4 times						
	Nodules/plant		Dry		Protein in plants	
Strain No.	No.	Weight(g)	weight plant(g)	%	weight plant(g)	% of control
Uninoculated	-	-	1.998	12.75	0.255	100
46	2.98	0.050	2.278	14.40	0.328	128.6
47	20.8	0.125	2.248	12.63	0.284	111.4
48	26.23	0.127	2.005	13.83	0.277	108.6
50	9.86	0.091	2.56	11.25	0.288	112.9
51	22.8	0.196	2.25	12.03	0.271	106.3
67	22.6	0.130	2.505	13.60	0.341	133.7

A 3 x 2 x 2 factorial design with three replicates was used to study the response of the three promising soybean varieties (Hale 3, Geduld, Bossier) to inoculant, nitrogen and to the combination of both. The plot size was 2.4 x 4.5 m, with a row spacing of 40 cm and planting distance of 6 cm within rows. Single superphosphate, at the rate of 300 kg/ha, was broadcast and worked in before sowing. "Solubor" at the rate of 10 kg solubor/ha was applied and was irrigated to each plot prior to sowing. A basal dressing of nitrogen at 200 kg N/ha as ammonium nitrate was applied in N treated plots as well as in plots treated with N plus inoculant. Seeds ef ech variety were inoculated with a mixture of strains 67 and 46 (see exp. I) in peat base and sown in plots treated with inoculant and in plots treated with N plus inoculant. Plots receiving neither inoculant nor nitrogen served as control.

Table 2 shows the yield of soybean varieties in the different regional research stations. It is clear that the application of inoculant plus N increased, significantly, the grain yield of all varieties over the control, but the extent of increase depended on both site and variety. The yield of variety Hale 3 increased by 101.8% due to inoculant, 84.8% due to nitrogen and by 112.1% due to the combination of both. The yield of the variety Geduld increased in the same order by 93%, 48.8% and 82.2% and that of Bossier by 102.7%, 82.1% and 99.1%.

2.3 Experiment III: Evaluation of the Residual Effect of Nitrogen Fixation

The contribution of rhizobia to soil productivity and the residual effect of inoculation on the subsequent crop, were evaluated at the Copperbelt and Luapula Regional Research Stations where soybean was rotated with maize grown in three virgin soil series, namely, Mufulira, Konkola and Misamfu. Mufulira soil is a sandy loam of pH 4.5, Konkola soil is sandy clay loam of pH 4.6 and Misamfu is a loamy sand of pH 4.5.

In a randomized block design of 3 treatments and 5 replicates and plot size of 7.2 x 25m the following three rotations were established: A - continuous maize (MMMM), B - soybean/maize (SMSM) and C - maize/soybean (MSMS). Lime and D compound 1/ basal dressing at the rate of 1 500 kg and 300 kg/ha respectively were applied to each plot separately before sowing. Soybean seeds were inoculated prior to sowing. Maize was top-dressed with 400 kg/ha ammonium nitrate (34.5% N) shortly after thinning.

1/ D compound: 10 - 20 - 10 + 10 kg S ($N-P_2O_5-K_2O$)

Table 2 EFFECT OF INOCULANT AND NITROGEN ON GRAIN YIELD OF SOYBEAN VARIETIES (kg/ha)1/

Location	Hale 3				Geduld				Bossier			
	Control	I	200 N kg/ha	I x N	Control	I	200 N kg/ha	I x N	Control	I	200 N kg/ha	I x N
1973-1974												
Mwinilunga	673	1041	544	350	623	1032	468	327	766	989	368	346
Malashi	477	1957	1660	1939	1161	1998	1509	2008	888	1990	1361	1844
Kabwe	259	1252	1198	1084	302	1368	1002	1460	297	1373	1431	1297
Mochipapa	111	1980	-	-	618	2351	-	-	139	1694	-	-
Buleya Malima	2235	2547	1517	2835	1552	2213	1273	1511	1914	2771	2429	2164
Mean	751	1735	1230	1552	851	1792	1063	1327	801	1763	1397	1413
1974-1975												
Nsekera	1137	1573	2792	2681	1191	2586	2886	2832	1129	2319	2921	3005
Lusitu	890	1795	2402	2307	854	1687	2089	2437	1128	1819	2357	2488
Mansa	710	1220	1300	1510	950	1875	1200	1575	675	1227	775	1300
Misamfu	1107	2213	1241	1782	1647	2214	1538	2510	985	2011	1327	1728
Mean	961	1700	1934	2080	1161	2091	1928	2339	979	1844	1845	2130
Mean 1973-74-75	856	1728	1582	1816	1006	1942	1496	1833	890	1804	1621	1772
% of Control		201.8	184.8	212.1		193.0	148.7	182.2		202.7	182.1	199.1

1/ I = inoculant. N = nitrogen.

In the Mufulira soil series at the Copperbelt Regional Research Station, nitrogen was determined in representative soil samples from each plot before basal application and after harvest. N was also determined in the seeds, rain water, weeds and the different parts of the harvested crops after being weighed from each plot separately.

The nitrogen balance sheet is presented in Table 3. The results indicate that, in the first season of the experiment, soybean fixed 170 kg N/ha (1062.5 kg crude protein) of which 86.4 kg were contributed to the soil. The amount of protein recovered by soybean grains amounted to 349 kg/ha. Maize, on the other hand, resulted in a negative nitrogen balance in both rotations A & C. The losses amounted to 65-68 kg N/ha of which 28.8 kg were lost from the original soil nitrogen.

Table 3 NITROGEN BALANCE SHEET IN MUFULIRA SOIL SERIES UNDER DIFFERENT ROTATIONS (kg N/ha)

	B SMSM1/	A MMMM	C MSMS
Nitrogen inputs:			
Soil	1420.800	1680.000	1478.400
Seeds	4.830	0.803	0.805
Fertilizers	30.000	168.000	168.000
Rain	5.962	5.962	5.962
Total	1461.592	1854.765	1653.165
Nitrogen outputs			
Soil	1507.200	1651.200	1449.600
Weeds	51.946	34.290	23.794
Grains	55.837	76.566	83.675
Plants	16.620	23.165	22.837
Miscellaneous	-	3.939	4.873
Total	1631.403	1789.160	1584.779
Balance	+169.811	- 65.605	- 68.386
Grain/loss in soil N	+ 86.400	- 28.800	- 28.800

S = soybean. M = maize.

The residual effect of soybean on the subsequent maize, expressed in grain yield, is indicated in Table 4. In all soil series and seasons the maize in the rotation (SMSM & MSMS) outyielded that in the continuous (MMMM) cropping, obviously due, at least in part, to the residual nitrogen contributed by the preceding soybean. In the last season (1976/77) the yields of the maize increased between 19.5 and 29.6% over the continuous maize, depending on the soil series and location of the experiment. The low yields experienced in the 1975/76 season in the Copperbelt Research Station were due to the adverse weather conditions during that season.

Table 4 YIELD OF SOYBEAN AND MAIZE IN DIFFERENT ROTATIONS, AND SOIL SERIES (kg/ha)

	Copperbelt Research Station						Luapula Research Station					
	SMSM1/		MMMM	MSMS		SSSS	SMSM		MMMM	MSMS		SSSS
Season	S Mufulira	M soil	series	M	S	Observation	S Mufulira	M soil	series	M	S	Observation
1973/74	1102		6497	6739		-	903		3947	3993		
1974/75		8249	6529		1859	809		4885	4830		1481	1506
1975/76	2149		2051	4335		1673	1770		4652	6156		1119
1976/77		6660	5334		2048	2148		6063	4679		2272	1151
			Misamfu soil series						Konkola soil series			
1973/74	963		5352	5141		-	933		4763	4226		-
1974/75		7325	6515		2063	883		6696	5644		1467	1506
1975/76	1835		1702	2015		1759	1907		5585	7363		1907
1976/77		6575	5500		2100	1611		7365	6148		1905	1634

1/ S = soybean. M = maize.

2.4 Experiment IV: Molasses Medium for Mass-scale Production of Rhizobium Culture

The encouraging results obtained in the experiments with rhizobia either in increasing the yield of soybean or the beneficial residual effect on the subsequent crop, gave rise to a programme on inoculant production for the use of soybean farmers. However, in view of the high prices of chemicals in Zambia, it was necessary to find a cheap medium for the mass production of Rhizobium cells to reduce the cost of inoculant manufacture.

Molasses is a rich substrate, and chemical analysis showed that it contains the necessary elements for the growth of rhizobia (Table 5). It is produced as a by-product of the sugar industry by the Zambia State Sugar Co. and is sold at a very cheap price. An experiment was therefore conducted to compare the rate and extent of growth of rhizobia in a molasses medium with that in a yeast extract mannital medium (YEM). For this purpose decolourized molasses was incorporated in a series of liquid media, containing 0.3% $CaCO_3$ and 0.1% yeast extract, at the rate of 3, 4, 5 or 6% (W.V.). YEM was used for comparison (Mannital, 10.0 g K_2HPO_4, 0.5 g $MgSO_4$, $7H_2O$ 0.2 g, NaCl 0.1 g, $CaCO_3$ 3.0 g, yeast extract 1.0 g, D.W. 1000 cc).

Table 5 CHEMICAL ANALYSIS OF MOLASSES

Sugars	Calcium	Magnesium	Potassium	Sodium	Phosphorus	Zinc
37%	0.81%	0.30%	3.4%	0.55 ppm	0.05%	150 ppm

Sterile 100 ml aliquots in 250 ml Erlenmeyer flasks, replicated 4 times, of each medium were inoculated with two drops of 72 hour old culture suspension of *Rhizobium japonicum* (strain 67) and allowed to grow on a rotating orbital shaker for 9 days at room temperature during which 10 ml aliquots were removed every 3 days from each flask, for growth density measurements using PYE Unicam SP6 Spectrophotometer at 425 mu. Measurement results in Fig. 1 show that out of the four concentrations of molasses, 5% yielded the best rate and extent of cell production within an optimum period of 6 days and even outyielded the YEM medium.

A comparison of the effect of the carbon source in the growth medium on the nitrogen fixing ability of Rhizobium and yield of soybean, was made using YEM or 5% molasses medium in field plot of 3 x 3 m. Results are given in Table 6. It showed that the change of carbon source (from mannital to sucrose) did not affect Rhizobium activity as evidenced by the non-significant difference in count and weight of nodules and yield. The 5% molasses medium was therefore used for inoculant production.

Table 6 EFFECT OF MEDIUM TYPE ON NODULATION AND YIELD OF SOYBEAN

Medium	Nodules No./10 plants	Nodules wt/10 plants (g)	Wt. of 1000 grains (g)	Grain yield kg/plot
YEM	86	8.6	171	2.365
Molasses 5%	119	7.8	169.5	2.345

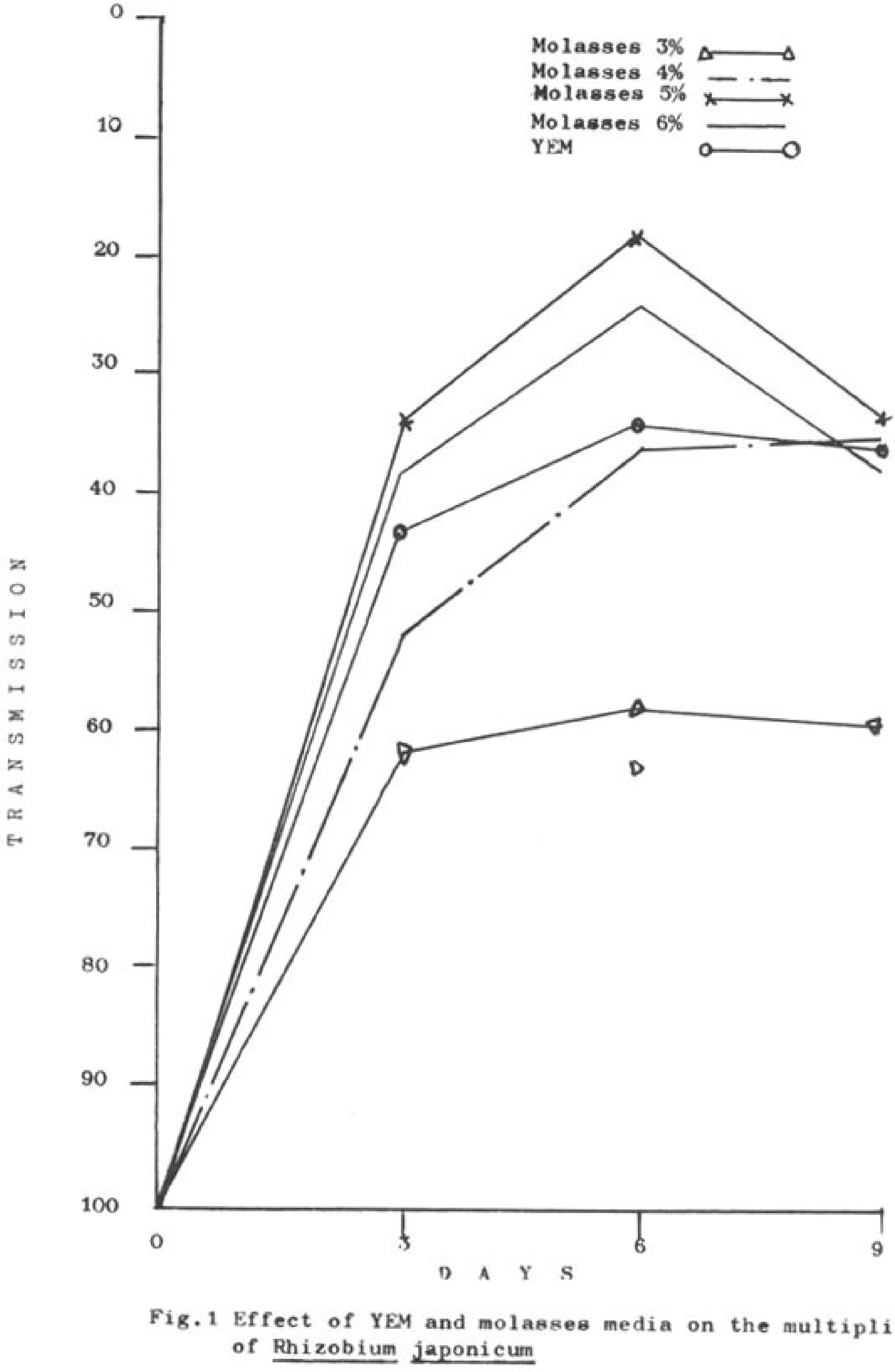

Fig.1 Effect of YEM and molasses media on the multiplication of *Rhizobium japonicum*

2.5 Experiment V: Interaction between Fungicides and Insecticides and Rhizobium

Seeds are subject to damage by pests during storage and/or when planted in soil. They therefore have to be protected by dressing with fungicides and insecticides. The possibility exists that such chemicals might exert an adverse effect on the inoculant. The effect of these chemicals on the inoculant was therefore investigated. Soybean seeds of the Bossier variety were dressed with each of the following chemicals at the rate of 2.5 g/kg seed:

a.	Captasan	88.0%	Captan	(65% active)	57.0% active
		12.0%	malathion	(25% active)	3.0% active
b.	Captan	88.0%	Captan	(65% active)	57.0% active
		12.0%	talc powder		
c.	Thiram	88.0%	thiram	(80% active)	70.0% active
		12.0%	talc powder		
d.	Thiram +	80.0%	thiram	(80% active)	70% active
	malathion	12.0%	malathion	(25% active)	3% active
e.	Malathion	12.0%	malathion	(25% active)	3% active
		88.0%	talc powder		

The dressed seeds were inoculated with peat inoculant before sowing in plots of 3.6 x 4.8 m, check plots were sown with inoculated undressed seeds, in a randomized block design of 6 replicates. The results of this experiment are shown in Table 7. At Copperbelt, none of the seed dressings exerted a significant adverse effect on nodulation and yield. At Msekera all seed dressings reduced the number of nodules significantly in 1974/75 and 75/76 and the yields in 1974/75. In 1975/76 only captasan decreased the yield significantly. Although none of the seed dressings at Magoye depressed significantly the number of nodules, all of them except thiram caused a significant decrease in yield in 1974/75 but not in other seasons. It seems that none of the seed dressings has a consistent effect.

2.6 Experiment VI: Interaction between Herbicides and Rhizobium

A pot experiment dealing with the effect of five herbicides viz. linuron 1.5 kg a.i./ha, turbutryne 80% W.P. 1.0 kg a.i./ha, alachlor 48% E.C. at 1.92 kg a.i./ha, trifluralin 956 g a.i./ha and nitralin 900 g a.i./ha was conducted in the greenhouse. Pots of the size 30 x 23 cm were filled with equal amounts of clay loam soil. The herbicides, at their recommended rate, were applied to the pots; 7 days before sowing in case of trifluralin and nitralin and immediately after sowin case of other herbicides. Pots receiving no herbicides served as control. Six replicates were maintained for each treatment. Soybean seeds of the variety "Bossier", inoculated with Rhizobium japonicum, in a peat base, were sown in the pots. Eight weeks after sowing the plants were removed carefully from the posts and observations on the number and fresh weight of nodules, dry weight of plants and their protein content were recorded, as in Table 8. Trifluralin and nitralin, though they reduced the number and weight of nodules and dry weight of plants, in relation to the control, did not affect the percentage of protein, but reduced its amount. Although linuron did not affect the number of nodules and the percentage of protein it lowered the weight of nodules, dry weight of plants and the amount of protein. Alachlor and turbutryne did not induce any adverse effect on Rhizobium.

It is premature to conclude that the adverse effects of some of these herbicides, apparent under greenhouse conditions, are applicable to field conditions before conducting field trials.

Table 7

EFFECT OF SEED DRESSINGS ON NODULATION AND GRAIN YIELD OF INOCULATED SOYBEAN (kg/ha)

	Magoye			Msekera			Copperbelt		
Treatment	1974/75	75/76	76/77	1974/75	75/76	76/77	1974/75	75/76	76/77
				Yield (kg/ha)					
Control	1250	1580	1710	2460	2020	944	2070	2222	1833
Captasan	645	1660	2022	1470	1490	977	2095	2477	1736
Captan	920	1720	1730	1525	1870	722	1990	2558	1806
Thiram	1120	1390	1797	1370	2290	866	1910	2292	1958
Thiram + malathion	780	1380	1852	1080	2120	1056	2440	2570	1972
Malathion	–	2060	1838	–	1920	773	–	2580	1819
				No. of nodules/plant					
Control	13.9	4.6	32.7	12.0	28.4	13.2	6.8	14.6	8.05
Captasan	7.3	1.6	28.9	1.6	4.1	12.4	2.6	11.5	9.06
Captan	15.6	2.8	23.4	2.9	14.3	6.4	3.4	17.4	6.95
Thiram	13.0	1.9	19.2	2.8	12.8	3.0	3.4	15.0	8.20
Thiram + malathion	10.7	1.7	14.4	1.1	13.4	5.2	3.8	20.4	5.78
Malathion	–	3.8	27.9	–	21.4	4.5	–	20.8	5.15

Table 8

EFFECT OF HERBICIDES ON NODULATION, WEIGHT OF PLANTS AND PROTEIN CONTENT OF INOCULATED SOYBEAN

	Mean of 3 plants replicated 6 times				
	No. of nodules	Weight of nodules (g)	Dry weight of plant (g)	Protein	
Treatment				%	wt/plant
Control	12.5	0.17	6.0	12.2	0.732
Lorox (Linuron)	12.2	0.12	4.5	12.6	0.567
Igran (Terbutryne)	12.7	0.18	5.7	12.3	0.701
Lasso (Alachlor)	11.4	0.18	6.3	12.4	0.781
Treflan (Trifluralin)	8.2	0.10	4.8	13.6	0.653
Planavin (Nitralin)	8.9	0.09	4.3	13.9	0.598

3. DISCUSSION

Protein malnutrition is an existing serious problem in Africa as well as in the major part of the Third World, so all means must be used to alleviate protein deficits. Therefore improvement in the livestock industry, for which the production of adequate pasture and fodder legumes is a necessary part, and in the production of edible legumes (i.e. soybean, groundnuts, beans, peas) is most urgent to counteract this deficiency. In this respect, increasing soil productivity plays an important role.

Nitrogen is of major importance in improving soil productivity but the manufactured nitrogen, at its present high prices, is beyond the means of the masses of poor farmers and raises the production costs for the able ones. The cheapest known source of nitrogen is that symbiotically fixed by rhizobia. Bearing this in mind, an extensive programme was initiated in Zambia to elucidate the role of inoculant in improving soil productivity and the yield of grain and forage legumes and consequently the amount of protein thereby produced.

Experiments on soybean inoculation revealed that the application of inoculant resulted in almost double grain yields and is as effective as nitrogen fertilizer, if not more so. From the economic point of view, the use of nitrogen fertilizer costs 44.52 Kwacha (K) per ha in terms of 120 kg nitrogen as ammonium nitrate 34.5% N (7 x 50 kg bags at K6.36 each) against K1.00 (K1 = US $ 1.25) for inoculant of seeds per ha. Thus the sole application of inoculant reduces the production costs by K43.52 per ha: a saving in expenditure of K43 520.00 per 1 000 ha.

The advantages of the symbiotic nitrogen are not limited to the legume itself but are passed on to the subsequent crop rotated with the legume. The present results show that, in one season, a soybean crop fixed 170 kg N/ha, of which the soil retained 86 kg. This contributed, at least in part, to an increase in the yield of the subsequent maize crop by up to 30% with no extra cost.

What has been achieved by soybean inoculant could apply to other grain and forage legumes, given the availability of efficient rhizobia, but of course the magnitude of the benefits is dependent on the legume and the crop in rotation.

The emphasis given to soybean inoculation and to the effect of pesticides and herbicides on the inoculant has not lead to neglect in the search for efficient rhizobia for other legumes. In greenhouse experiments, efficient rhizobia have been selected for groundnuts and *Glycine wightii* and will be tried in field experiments in due course; work on beans, lucerne and *Stylosanthes* is in progress.

The valid results achieved by soybean inoculation led to commercial inoculant production. Mount Makulu Research Station produces inoculant for about 1 500 ha soybean per season (which increased to 2 500 ha in 1977) using simple means and without sophisticated equipment and at the cheapest possible cost by utilizing locally produced molasses as the medium for growing rhizobia instead of depending on costly imported chemicals. The use of molasses reduced the cost of the production medium by 85% of that of the YEM.

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Paper 16

THE POTENTIAL CONTRIBUTION OF NITROGEN FROM RHIZOBIA - A REVIEW

by

A. Ayanaba [1]

1. INTRODUCTION

Farmers have for centuries depended and continue to depend on natural bush regeneration and the consequent build-up in soil fertility during fallow periods as a source of nitrogen for food crop production, but the uncontrolled increase in the population of man has increasingly placed more and more of a strain on the land use system in traditional agriculture. There are increasingly shorter periods of fallow and thus less accretion of nutrients. Short term solutions have been to supplement the nitrogen mineralized from organic matter with chemical fertilizers. This is often not enough. It was estimated by Hardy and Holsten (1973) that 36.5 million tons of nitrogen fertilizers were utilized in agriculture in 1973 on a global basis. This represented only one-fifth of the amount fixed biologically, however.

Chemical nitrogen fertilizers are costly to produce, are not always completely taken up by crops (e.g. Hinson and Hartwig 1977, quote efficiency values of 30-60%) and their use may be associated with certain environmental problems (Ayanaba 1977a). Nevertheless, man must continue to rely on chemical nitrogen fertilizers for crop production, particularly of cereal crops.

By contrast to the chemically fixed nitrogenous fertilizers, biologically fixed nitrogen has certain advantages. The legume rhizobia have the unique ability to reduce atmospheric nitrogen at normal pressures and temperatures when living in association with a suitable host under the proper edaphic and climatic conditions. However, even under the best systems of management, effectively nodulated legumes still utilize nitrogen from exogenous sources, especially in the pre-linear phase of growth (Hoglund 1973).

Our aim should be to make as much use as possible of the ability of rhizobia to fix atmospheric nitrogen. In reviewing work done on this subject, it is my aim to discuss the potential and actual contribution of rhizobia to nitrogen supply. It is understood that this will aid in food crop production and improved soil fertility. Consequently, the link between nitrogen fixation and these topics will not be discussed.

Inasmuch as the potential of nitrogen fixation in Africa is not fully tapped, I propose to discuss factors influencing nitrogen fixed by rhizobia, after brief treatment of the topic of the legume-Rhizobium symbiosis. Subsequently, I shall review work on quantities of nitrogen fixed. Finally, I propose to discuss areas needing further work so as to maximize the potential contribution of nitrogen from rhizobia in the region.

2. NITROGEN FIXATION IN THE LEGUME-RHIZOBIUM SYMBIOSIS

A simplified way to write the equation for biological nitrogen fixation is:

$$N_2 + 3\,H_2 \xrightarrow{6e} 2\,NH_3$$

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The nitrogen fixation reaction is catalyzed by nitrogenase, an enzyme found in bacteroids of legume root nodules. Nitrogenase consists of two moieties: Component I is an iron-molybdenum containing protein with a molecular weight of 180 000, and Component II is an iron-sulphide containing protein with a molecular weight of 51 000. The reaction shown above also requires ATP as energy source, a reductant as an electron source and molecular nitrogen as an electron acceptor. In the legume-Rhizobium symbiosis, the legume supplies the carbohydrate that fuels the reaction and so is indispensable to this reaction.

Recent attempts with genetic engineering techniques are aimed at transferring nitrogen—fixing (nif) genes from nitrogen-fixing organisms like rhizobia to non-fixing organisms or to directly incorporate nif genes into plants. Although these are laudable efforts at the frontiers of science, the dividends are not likely to be realized soon. Thus, those of us working in the developing world need not invest time and money in this type of research. Rather, we should keep one eye on developments of these more novel techniques and the other eye on the more established, standard techniques of increasing nitrogen fixation by legume rhizobia. According to some reports the increase in nitrogen fixation by these novel techniques is not going to be without detrimental side-effects (see, for example, the summary by Marx (1977) on the latest meeting on the topic).

For nitrogen fixation in the symbiosis to proceed optimally an appropriate legume must be nodulated by an efficient rhizobium and climatic and soil conditions must be favourable. Nitrogen fixation may commence as early as seven days from sowing if plants are well nodulated. If plants are not well nodulated, fixation starts later. In soybeans, for example, fixation may start as late as 20-30 days after sowing, but once started, the doubling time is every six to ten days, until late flowering when it falls rapidly (Hinson and Hartwig 1977).

In much of the tropics we rely mainly on naturally nodulated legumes for nitrogen fixation. The data in Table 1 clearly demonstrate that different, uninoculated legumes have different efficiencies in nitrogen fixation. Even within the same species, different cultivars sown at the same site exhibit different fixation capacities (Ayanaba and Nangju 1977).

Inoculation of legume seed has been carried out in several African countries. Some of the reports deal with inoculation of introduced legumes, where responses to inoculation would be expected. Reports have come from Sierra Leone (Kamara 1973), Ghana (Mercer-Quarshie and Nsowah 1975), Ivory Coast (Assa and Edi 1975), Nigeria (Tewari 1962; Ezedinma 1964; Agboola 1971; Rotmi 1972; Kang 1975; Ayanaba and Nangju 1977), Cameroun (Silvestre 1970), Zaire (Bonnier 1957; Bonnier and Seeger 1958), Rwanda (Camerman and Deschuytener 1973; Camerman and Hakizimana 1975), Zambia (Zayed, pers. commun.), Kenya (Robinson 1963; de Souza 1969; Keya 1977), Senegal, Egypt (Hamdi 1976), Tanzania (Chowdhury 1977a) and Sudan (Mahdi and Habish 1975). Many more reports undoubtedly exist. It appears that in Zambia, Kenya, Rhodesia and Rwanda, legumes are routinely inoculated by commercial farmers. The inoculated legumes are introduced ones such as soybean, and the responses to inoculation are understandable. Where indigenous legumes are grown, improvement in nitrogen fixation through seed inoculation would be harder to show. For example, in cowpea growing areas, cowpea rhizobia are abundant (Sellschop 1962: Ayanaba, unpublished) and inoculation is not likely to give significant responses (Ayanaba and Nangju 1977; Chowdhury 1977a). Similar observations have been made elsewhere (e.g. Kenya, Sudan, Egypt).

Table 1

NODULE EFFICIENCIES OF NATURALLY NODULATED TROPICAL FORAGE, GRAIN AND TREE LEGUMES
(Ayanaba, unpublished)

Legume	Maximum nodule efficiency μmoles C_2H_4/g dry nod./hr
Grain and forage	
Psophocarpus tetragonolobus	193
Alysicarpus vaginalis	134
Macuna utilis	117
Crotolaria sp.	111
Vigna unguiculata	103
Cajanus cajan	85
Sphenostylis stenocarpa	60
Phaseolus lunatus	59
Kerstingiella geocarpa	56
Tree and shrub	
Indigofera arrecta	334
Sesbania sp.	133
Tephrosia sp.	87
Leucaena leucocephala	36

Table 2

NODULATION OF SIX SOYBEAN CULTIVARS BY INTRODUCED AND INDIGENOUS RHIZOBIA IN TANZANIA
(Chowdhury 1977a)

	Total numbers of nodules per plant for cultivars shown					
Inoculum	IH 192	HLS 223	9H/100/5	7H101	Improved Pelican	Hernon 237
CB 1809	32	19	33	41	6	47
CB 1795	30	28	36	42	16	50
R 3409	18	27	17	36	10	18
R 3411	12	19	24	44	9	25
R 3417	32	45	26	59	5	48
Peat	21	19	25	35	8	20
Uninoculated	19	12	15	28	2	19
Mean	23	24	25	41	8	32

S.E. cultivar means ± 3.4

S.E. inoculum means ± 3.9

Table 3

EFFECT OF SEED INOCULATION WITH RHIZOBIUM ON GRAIN YIELD OF FOUR CULTIVARS OF SOYBEAN AT TWO SITES IN TANZANIA
(Chowdhury 1977b)

Inoculum	Grain yield (t/ha) of indicated variety grown at site shown									
	IH/192		HLS 223		7H/101		3H/149/1		Mean	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
CB 1809	2.05	1.04	2.71	1.35	2.44	1.67	2.28	1.09	2.37	1.29
M 15	2.39	1.00	2.82	1.29	2.21	1.47	2.65	1.78	2.52	1.39
M 17	3.02	1.21	3.50	1.36	2.30	1.54	2.57	1.45	2.85	1.39
M 18	2.80	1.41	2.64	0.98	2.40	1.73	2.26	1.20	2.52	1.33
M 19	2.83	2.78	2.86	1.61	3.23	2.39	3.13	2.05	3.01	2.21
Mixture	2.92	0.95	3.84	1.38	3.17	1.09	2.29	0.91	3.05	1.08
Uninoculated	2.13	1.62	2.38	1.15	2.60	1.62	2.42	1.54	2.38	1.48

LSD (0.05) Inoculation mean for Site 1 = 0.88 and for Site 2 = 0.44.

Reports that introduced legumes such as soybeans do not respond to inoculation require further study. Such reports have been received from Nigeria (Lot, pers. commun.; Asenime, pers. commun.), Zaire (Mbe-Mpie, pers. commun.) and Tanzania (Chowdhury 1977a & b and Tables 2 & 3). Indeed, these observations were briefly mentioned in a symposium in 1975 (Ayanaba 1977b; Chowdhury 1977a) and discussed at some length by Agboola and Ayanaba (1977). However, the identity, competitive ability and effectiveness of the rhizobia involved remain to be demonstrated.

3. FACTORS LIMITING NITROGEN FIXATION

Before considering quantities of nitrogen fixed by rhizobia, let us first examine some of the factors that are likely to limit nitrogen fixation under tropical conditions. There are four major factors which will in general determine the quantities of nitrogen fixed by rhizobia: climatic, edaphic and biological factors and host plant. The effects of these factors on nodulation and nitrogen fixation are well known and documented (e.g. Vincent 1965; Bergersen 1977; Sinha 1977; and several Chapters in Quispel, 1974). However, data relating to the tropics, and particularly tropical Africa, are few. Where the data exist, they will be presented in the discussion below.

3.1 Climatic Factors

Climate is the principal environmental factor determining nitrogen fixation. Thus, the effects of radiation, rainfall, air temperature, and gas (especially CO_2) concentration influence nitrogen fixation. The most important appear to be radiation, CO_2 concentration, temperature and relative humidity.

Because fixation is dependent on photosynthate, adequate radiation is crucial. The date of Hardy and Havelka (1976), Mahdi and Habish (1975) and Phillips, Newell and Hassell (1976) clearly show this. When radiation is adequate, CO_2 may limit nitrogen fixation (Hardy and Havelka 1976). The cause of the cessation of fixation in the late flowering stage has been attributed to source-sink effects (Vest et al 1973; Ham, Lawn and Brun 1976) but Hinson and Hartwig (1977) argue that there may be other explanations. In support of the hypothesis that the developing seed competes better for photosynthate than nodules, Ham et al (1976) offer the following argument. In their work, acetylene reducing activity per soybean plant increased during flowering, reached a maximum near the end of flowering and declined sharply during early pod-fill. Treatments to enhance the photosynthetic source-sink ratio (i.e. by supplementary light and depodding), maintained nitrogenase activity well above the control, while shading and defoliation, which reduce the source-sink ratio, decreased it below the control. The authors interpreted the results as evidence that nitrogen fixation declined during pod-fill as a result of inadequate supply of assimilates to the nodules.

Temperature, particularly of the root zone, but also of the aerial parts because of effects on relative humidity do affect fixation. Galleti et al (1971), Dart and Day (1971), Dart et al (1976) and Mahdi and Habish (1975) furnish data on the effects of root temperature on fixation in tropical legumes. In general, plant-Rhizobium combinations of the tropics have higher temperature optima (see below). Ayanaba and Lawson (1977) concluded from a recent study that relative humidity limits nitrogen fixation at certain periods of the day (Fig. 1).

The effects of flooding are usually transient for some legumes (Minchin and Pate 1975; Sprent 1976; Minchin et al 1977) but some legumes are unfavourably affected by too much water. The effects of drought are to decrease fixation (Huang, Boyer and Vanderhoef 1975; Sprent 1976).

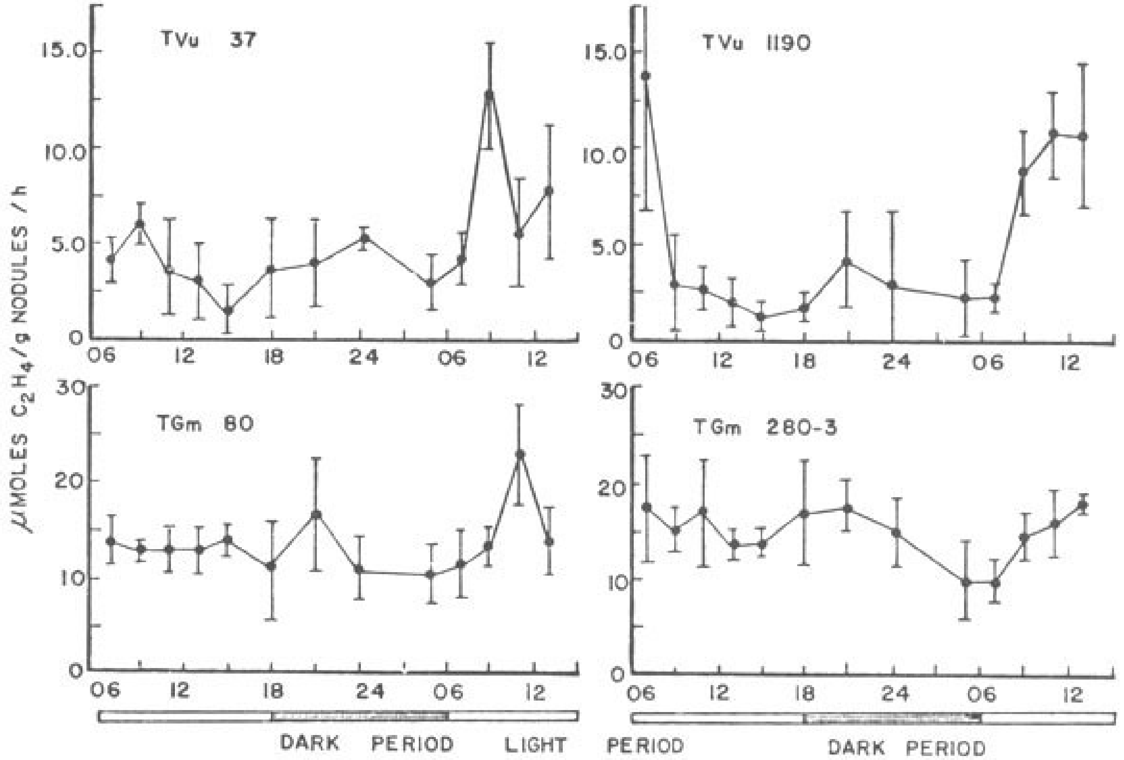

Fig. 1 Diurnal changes in C_2H_2 reduction in nodulated roots of cowpeas (TVu 37 and TVu 1190) and soybeans (TGm 80 and TGm 280-3) harvested 55-56 days after planting. Vertical lines are standard errors of means of replicates

Table 4 SYMBIOTIC PERFORMANCE OF FIVE *RHIZOBIUM* STRAINS WITH THREE *CICER ARIETINUM* VARIETIES AT TWO ROOT TEMPERATURES (adapted from Dart *et al* 1976)

Variety	CB 1189		27A2		27A9		Ca-1		Ca-2	
	23°C	30°C	23°C	30°C	23°C	30°C	23°C	30°C	23°C	30°C
	Dry weight of nodules/plant (mg)									
Deshi	89	56	79	55	84	82	82	64	87	76
Kabuli	98	96	93	65	108	90	78	93	103	85
Iranian	100	86	86	82	96	70	104	81	96	104
	Nitrogen fixed (mg/plant)									
Deshi	26	8	21	6	27	13	28	12	28	17
Kabuli	30	10	27	3	35	8	27	17	33	21
Iranian	33	11	29	8	32	9	35	12	21	22

3.2 Edaphic Factors

The many soil factors that affect rhizobia and their nitrogen-fixing capacity include pH, organic matter, temperature, soil nutrients (especially N, P, Ca, Mn, and Mo), and soil moisture. All these effects are more generally discussed by Vincent (1965), Dart et al (1976) and Sinha (1977), and specifically as related to the tropics by Kang, Nangju and Ayanaba (1977), Ayanaba (1977b) and Edwards (1977). Temperature of the rooting medium and moisture have been discussed above.

Temperature will decrease nitrogen fixation in most legumes when above 30°C. The data in Table 4 show that the appropriate host-strain combination can be selected. In this particular study, the authors concluded that the effect of high temperature was to reduce nodule nitrogenase activity, possibly by accelerating basal nodule senescence.

The inhibition of nodulation and nitrogen fixation by inorganic nitrogen is well known. In general, if nitrogen must be added to get the plants through the "hunger period" it must be just enough to maintain the plants until nodules are fixing. Hoglund (1973) showed that in nodulated lucerne, response to inorganic nitrogen was limited to the pre-linear phase of growth.

Rhizobia of the cowpea group fall mainly into the group of alkali-producing strains; they are abundant (greater than 10 000/g soil) in many acid soils (Ayanaba 1977c). Odu, Fayemi and Ogunwale (1971) concluded from their work that there was no need to lime some Nigerian soils to increase nitrogen fixation. However, they were dealing with soils that were not very acid.

Introduced rhizobia such as Rhizobium japonicum survive well in soils with pH values above 6.0 (see Table 5). In acid soils, R. japonicum does not survive well (Danso, unpublished). Where acidity is a problem, seed pelleting with lime is well advised (Norris 1972; Bandoja, Altamiro and Iswaran 1974).

Table 5 THE EFFECTS OF SEED INOCULATION ON THE INCREASE IN NUMBERS OF RHIZOBIUM JAPONICUM ESTIMATED BY THE PLANT INFECTION TECHNIQUE
(Ayanaba, unpublished)

Period	Inoculant	Number of rhizobia/g soil in the indicated soil series	
		Apomu series	Egbeda series
Pre-inoculation	None	6	1
Post-inoculation	None	<10	5
	Nitragin	$>7.02 \times 10^3$	$>7.02 \times 10^3$
	Nitrogerm	$>7.02 \times 10^3$	$>7.02 \times 10^3$

Phosphorus is required in large quantities for nodulation and nitrogen fixation (Vincent 1965). Many tropical soils are low in phosphorus or have high P-fixing capacities, and very often a phosphorus response can be shown (e.g. Tewari 1965; Ayanaba and Nangju 1977). In some Nigerian soils lacking sulphur, fertilizing with a mixture of rock phosphate and elemental sulphur to give a P : S ratio of 1 : 0.7 has been found useful (Bromfield 1975). The vesicular-arbuscular mycorrhiza offer an opportunity to make good use of soil phosphorus or rock phosphates. Islam, Ayanaba and Sanders (1976) have demonstrated an increase in modulation and nitrogen fixation in legumes inoculated with mycorrhiza.

In acid and flooded soils, aluminium and manganese toxicity can reduce nitrogen fixation (Franco and Dobereiner 1971; Holding and Lowe 1971; Martini et al 1974) but selection of appropriate host-strain combinations can circumvent this. Mutants tolerant to these, and indeed, several environmental variables can be developed.

Fungicides, herbicides and insecticides added to seed or soil to control pests are also potent inhibitors of rhizobia (Curley and Burton 1975; Swamiappan and Chandy 1975; Odeyemi and Alexander 1977). Here, too, mutants resistant to several pesticides can be developed or selected.

3.3 Biological Factors

The most important factor influencing nitrogen fixation is the presence of an efficient rhizobium. The survival, effectiveness and competitive ability of rhizobia in relation to tropical conditions have recently been reviewed by Alexander (1977), Obaton (1977) and Sinha (1977).

At the centre of diversity of a given legume, several strains of rhizobia are likely to have been selected for different cultivars. Thus, strains nodulating the same cowpea cultivar effectively (Burton 1952) or differential nodulation response of several cultivars sown in uninoculated soil (Table 6) are common. Under these conditions, competition for nodulation sites will be keen. According to Allen (1962) about 25% of strains in soil are of the most desirable types. Consequently it is crucial that we select the most efficient.

Table 6 NODULE FORMATION AND EFFICIENCY OF SEVEN UNINOCULATED COWPEA CULTIVARS GROWN IN ONE SOIL
(Ayanaba and Nangju 1977)*

Cultivar	No. of nodules per plant	Dry weight of nodules per plant (mg)	μmoles C_2H_4 /g nodules/ hr
TVu 37 (Pale green)	44b	283.4a	89.3a
TVu 76 (Prima)	40b	198.5b	53.5b
TVu 3616 (K 2809)	52b	92.8c	53.2b
TVu 6198	71a	202.3b	46.5b
TVu 1190 (V.U.5)	39b	263.0ab	94.7a
TVu 3629 (Ife brown)	54b	324.6a	90.0a
TVx 29-17	40b	175.5bc	53.3b

* Numbers followed by the same letter in a column are not significantly different at the 1% level for dry weight of nodules per plant (mg) and nodule activity; they are not significantly different at the 5% level for no. of nodules per plant.

Because of the variety of strains available at the centre of diversity or origin of a legume, responses to inoculation should rarely, if at all, be expected.

This is indeed the observation. However, with modern breeding and selection techniques legumes can be bred away from the rhizobia, or newer yield plateaux may be such that the rhizobia can not supply much of the needed nitrogen. There is clearly the need for the legume breeding programme and the Rhizobium strain selection to be conducted in parallel. This is the policy now being pursued at the International Agricultural Institutes.

Other biological factors influencing nitrogen fixation are pests and diseases. Some of these are so fundamental to crop production that unless they are curbed, there would be no plant to support rhizobia. A case in point is cowpea. This crop is so susceptible to insect pests that these constitute the major limitation to cowpea production. Agboola and Ayanaba (1977) concluded from their review of the literature on cowpea work in Nigeria, the major producer of cowpea, that all workers were agreed on this being the major limitation to cowpea production. Under the low yield conditions, moderately effective rhizobia could supply all the nitrogen contained in 600 kg grain. For, assuming that cowpea has about 25% protein, the seed would contain 24 kg N.

It is reported that viruses (Tu, Ford and Quiniones 1970; Venkataraman and Subba Rao 1974) and nematodes (Epps and Chambers 1962; Taha and Raski 1969; Hussey and Barker 1974; Baldwin, Barker and Nelson 1975) may or may not affect nodulation and nitrogen fixation. Where these organisms affect fixation it will be through competition for root colonization, reduction in the photosynthetic capacity due to leaf or root removal, and respiration requiring photosynthate. The work of Sitaramaiah and Singh (1975) suggested that Monochus sp. could ingest and transmit rhizobia.

Non-phytopathogenic soil inhabitants also affect nitrogen fixation through the indirect effects of keeping a balance on rhizobial populations. Predation by protozoa (Alexander 1977; Danso 1977), parasitism by Bdellovibrio (Alexander 1977) and by phages (Alexander 1977) are some likely activities in soil which affect fixation. At some stage, these will need to be examined in tropical soils.

3.4 Plant Types

Although rhizobia have joined the ranks of the free-living nitrogen fixers (see the review by Dilworth and McComb 1977) this remains to be shown in soil. Moreover the importance of free-living rhizobia to soil fertility has to be demonstrated. Until then, the plant remains the only place within which rhizobia can fix economically significant quantities of nitrogen.

There are differences in abilities of plants to utilize fixed nitrogen. The competition for carbohydrate by hydrogenase of rhizobia (Schubert and Evans 1976) affect the amount of fixed nitrogen available for utilization. Data on the utilization and redistribution of fixed nitrogen in a tropical legume - cowpea - have been furnished by Eaglesham et al (1977). The data suggest that different legumes have different abilities to redistribute fixed nitrogen into either seeds or vegetative matter. Recent data from the International Institute of Tropical Agriculture (Pulver, unpublished) on nitrogen utilization in cowpea and soybean agree with this. These observations are relevant in the choice of legume for protein yield or soil fertility improvement.

4. QUANTITIES OF NITROGEN FIXED BY RHIZOBIA

4.1 Measurement of Fixed Nitrogen

The use of $^{15}N_2$ as a tracer in quantifying nitrogen fixation by rhizobia (Burris and Wilson 1957) is about the most definitive method available. However, the method is not practical for field use, is expensive and time-consuming by comparision to other methods. There are other, less precise and less accurate but nevertheless more facile ways to quantify nitrogen fixation. These include: (a) ^{15}N fertilizer methods (Ham 1977; Bremner 1977); (b) the "A value" method proposed by Fried and Broeshart (1975); (c) the use of nod-nonnod isoline of soybeans (Weber 1966), and (d) the use of a cereal and a legume. There are other methods (e.g. using a cereal crop to estimate residual nitrogen) but all essentially also measure nitrogen fixed by other sources, nitrogen coming from rain, etc. Indeed, one must distinguish between nitrogen fixed and residual nitrogen. The onset of rains after the dry season brings about a flush in mineralization (the Birch effect) and losses of fixed nitrogen are unavoidable. As such, nitrogen measured through crop removal must not be misconstrued as the absolute amount of nitrogen fixed.

4.2 Quantities of Nitrogen Fixed

The data in Table 7 show nitrogen contents of various legume parts. This will serve as background material for discussing the quantities of nitrogen fixed and removed in seed or retained in plant debris. Because the nitrogen distribution and utilization pattern differ with each plant type, we must select legumes to fit our needs. Selecting legumes for seed, for forage or for soil fertility purposes will differ.

Table 7 THE NITROGEN CONTENT OF LEGUME PARTS
(assembled from various sources by Henzell & Vallis 1979)

Part of plant	% N
Seeds	4.0 - 6.0
Leaves	2.6 - 5.0
Stems	1.2 - 1.8
Roots	1.6 - 2.4
Nodules	3.9 - 6.5
Pods	3.1 - 4.2
Whole plants	2.0 - 3.0

4.2.1 Nitrogen fixed in grain legumes

The data in Tables 8-9 indicate that nitrogen fixed in tropical grain legumes ranges from 40 to 450 kg N/ha. The primary aim of increasing fixation in these crops is for increased seed protein. Most of the fixed nitrogen ends up in seed. Our aim should be to select plant-rhizobia combinations such that the plant can obtain over 90% of its nitrogen from rhizobia. The plants should redistribute most of the nitrogen into seed. The seed should be the strongest sink for nitrogen fixed such that seeds contain nitrogen at the upper limit of the figures in Table 8.

Estimates of the quantities of nitrogen fixed by R. japonicum in the USA for soybean yields of 2500 - 3000 kg/ha range from 80-160 kg/N/ha or about 25-60% of the nitrogen in seed (see Table 10. Note there is some N in unharvested parts). Although Hinson and Hartwig (1977) and Vest et al (1973) present data to show that soybean obtains much of its nitrogen from

Table 8

ESTIMATES FROM FIELD EXPERIMENTS ON NITROGEN FIXATION IN TROPICAL GRAIN LEGUMES
(assembled from various sources by Nutman 1976 and Ayanaba 1977a)

Crop	Range kg N/ha	No. of estimates
Glycine max	64 - 206	3
Vigna unguiculata	73 - 240	3
Vigna radiata (mung bean)	61 - 342	2
Arachis hypogaea	72 - 240	3
Cajanus cajan	96 - 280	3
Cicer arietenum (chickpea)	103	1
Canavalia ensiformis	49	1
Cyamopsis tetragonolobus (guar)	41 - 220	2
Lens culinaris (lentil)	88 - 114	1
Pisum sativum	52 - 77	1
Vicia faba	45 - 552	4
Calopogonium mucunoides	370 - 450	1

Table 9

QUANTITIES OF NITROGEN FIXED IN GRAIN LEGUMES UNDER EGYPTIAN CONDITIONS
(Risk, quoted in Hamdi 1976)

Grain legume	N fixed, kg/ha
Lupinus sp. (lupin)	139.7
Canavalia ensiformis (horse bean)	136
Cicer arietenum (chickpea)	105
Trigonella foenum-graecum (fenugreek)	98
Lens culinaris (lentil)	83
Arachis hypogaea (groundnut)	79
Glycine max (soybean)	40

symbiosis, it has been suggested that soybean plants in the USA have been bred on inorganic N fertilizers, thus explaining the lower values of symbiotically fixed nitrogen which ends up in seed.

4.2.2 Nitrogen fixed in forage legumes and cover crops

The symbiosis between these legumes and rhizobia results in fixation of up to 862 kg N/ha/year according to some estimates (Table 11). It is pertinent

Table 10 ESTIMATES OF NITROGEN FIXED IN SOYBEANS IN THE USA (tabulated from information provided in Vest et al 1973)

Soybean	Seed yield (kg/ha)	Estimate of N fixed (kg N/ha)	N derived from fixation (%)
Delmar	2600	160	59
Scott	2200	93	41
Nod-Nonnod	2800	84	40
Kent	N.D. 1/	148 - 163	25
Kent	2300	164	N.D.

1/ N.D. = No data provided.

to point out that because some of these legumes are frequently grown with grasses, the continued transfer of fixed nitrogen from sloughed-off or dead and decomposed nodules and roots could enhance increased fixation. In symbioses of this type, selected rhizobia should be highly efficient fixers and plants should preferentially re-distribute fixed nitrogen to vegetative matter rather than seeds. This can be done as has been demonstrated by Australian workers.

Table 11 ESTIMATES FROM FIELD EXPERIMENTS OF NITROGEN FIXATION IN TROPICAL FORAGE AND GREEN MANURE LEGUMES (compiled from various sources by Nutman 1976; Ayanaba 1977; and Whitney 1977)

Legume	Range kg N/ha/yr	No. of estimates
Centrosema pubescens	126 - 395	5
Crotolaria sp.	110 - 200	1
Desmodium canum	95	1
D. intortum	400	1
D. uncinatum	125	1
Phaseolus atropurpureus (siratro)	291	1
Pueraria phaseoloides (kudzu)	100 - 862	3
Stylosanthes gracilis	108 - 197	2
Stylosanthes sp.	93 - 220	3
Glycine wightii	160 - 450	2
Mixture of centro & stylo	115	1

The data in Table 12 indicate that by selection of the appropriate legumes and grasses and through good management the amounts of nitrogen fixed and transferred can be greatly increased.

Table 12 NITROGEN CONTRIBUTIONS BY DESMODIUM INTORTUM UNDER DIFFERENT CUTTING REGIMES AND IN MIXTURES WITH PANGOLA DIGITGRASS (DIGITARIA DECUMBENS) AND KIKUYUGRASS (PENNISETUM CLANDESTINUM) (Whitney 1977)

Grass in mixture	Management	Percent legume	Apparent kg N/ha/yr*	
			Fixed	Transferred
Pangola	Cut 5 wks at 5 cm	40	85a	- 3a
	Cut 5 wks at 13 cm	50	125ab	0a
	Cut 10 wks at 13 cm	58	313b	53b
Kikuyu	Cut 5 wks at 5 cm	44	74a	- 5a
	Cut 5 wks at 13 cm	55	176ab	15ab
	Cut 10 wks at 13 cm	55	316c	66b

* Numbers in a column followed by the same letter are not significantly different at the 5% level.

Jones (1942) in Kenya used indirect soil nitrogen measurement to calculate that Glycine wightii added the equivalent of 140 kg N/ha/year over a five-year period. In the Sudan, Musa and Burhan (1974) showed the potential of several forage legumes as nitrogen sources (Table 13). They did not quantify the proportions fixed, however.

4.2.3 Nitrogen fixed in tree and shrub legumes

Because it is difficult to do so, the quantities of nitrogen fixed by rhizobia living in symbiosis with tree and shrub legumes have been little studied. Nitrogen fixation in Leucaena leucocephala is reported to be 74-584 kg N/ha/year (Nutman 1976; Whitney 1977); in Sesbania cannabina the value is 542 kg N/ha/year (Nutman 1976) and in the acacias it is 150-240 kg N/ha/year (Bryan 1962). Nitrogen fixation in Tephrosia, Glyricidia, Cassia (those that nodulate), Parkia and Indigofera could be substantial. Recent work at IITA has shown that many of these plants nodulate well and nodules on seedlings of some of them actively reduce acetylene (Table 1), indicating high fixation potential.

Many of these legumes are frequently the only ones which can withstand prolonged dry seasons and droughts (such as occur in the Sahel). They have manifold uses: food, fodder, medicinal, industrial, as poles, hedges, etc. A plea for more attention to these legumes was made by Agboola and Ayanaba (1977).

5. TOWARDS A REALIZATION OF THE FULL POTENTIAL OF NITROGEN FIXATION BY RHIZOBIA

It is my belief that the potential contribution of nitrogen from rhizobia is not fully tapped in Africa. There are four major reasons for this. First, there is not sufficient specialized, trained manpower to tap this potential. This point has been dealt with adequately elsewhere (Ayanaba 1977a & b).

Second, we do not know about the ecology of rhizobia in our soils and as such do not know the full extent of our potential. We need to know the diversity of indigenous rhizobia, their survival, efficiency, infectivity, and competitive abilities.

Third, we do not have an accurate assessment of our legumes, particularly the trees, browse plants, and forage legumes. The energy with which several countries are attacking soybean nodulation problems is encouraging.

Fourth, more studies (i.e. definitive studies) are required to quantify nitrogen fixed by rhizobia. There are few accurate data in Africa on this. Until we know the efficiencies of our strains and can compute their actual contributions to protein production and soil fertility - until we can do this, then we do not really know the full potential of the rhizobia of our legumes.

Table 13 NITROGEN YIELD (kg N/ha) OF VARIOUS FORAGE LEGUMES IN THE SUDAN (Musa and Burhan 1974)

Season	Legume	Leaves	Stems	Roots	Nodules	Fruits	Total N
1970-71	Phillispesara	90.9	53.1	5.4	1.7	13.8	164.9
	Clitoria	80.3	61.8	17.8	1.0	10.4	171.2
	Lubia	77.6	45.0	5.7	3.2	25.0	156.4
	Groundnuts	42.9	19.3	9.4	4.4	96.4	178.7
	Green gram	69.2	37.8	15.1	7.4	12.1	141.6
	Cowpea	34.3	21.3	4.2	3.2	16.8	79.8
	Soybean	37.3	17.5	9.1	2.5	0.0	64.4
1971-72	Phillispesara	96.9	93.9	15.8	4.4	24.5	235.5
	Clitoria	81.5	86.5	22.5	2.0	10.4	202.9
	Lubia	93.7	80.8	12.4	5.7	29.6	222.2
	Groundnuts	44.0	26.7	10.1	7.2	95.5	183.9
1972-73	Phillispesara	83.8	71.9	9.6	2.7	35.1	203.1
	Clitoria	90.4	54.1	17.0	2.5	46.0	210.0
	Lubia	79.8	56.3	10.4	6.7	23.0	176.2
	Groundnuts	39.0	21.7	10.6	5.9	158.9	236.1

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Paper 17

ORGANIC RECYCLING IN AGRICULTURE: SOME RESEARCH NEEDS

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1. INTRODUCTION

Organic recycling in agriculture can be defined as the return of all unconsumed organic residues, and all natural organic manures, to the soil, to support further crop and animal production. The term is also used to cover the deliberate production of organic material for use as a soil additive, although this represents cycling rather than recycling of organic materials. The importance of recycling organic materials is to conserve the nutrients contained in them, to conserve the energy embodied in them, and to take advantage of the favourable effects that organic materials may have on soil physical conditions as regards plant growth.

The general principles of organic recycling have been long established. Nevertheless there continues to be a great waste of resources, associated with the burning of grassland, of crop residues, of fallow vegetation, and the failure to utilize other organic residues. Why is this? The answer is not entirely because of ignorance, but because it is either not convenient or not economic to utilize them. Research related to organic recycling should therefore be aimed at examining factors which determine whether or not it disrupts existing agricultural practice to utilize organic residues more efficiently, and what are the relative economic advantages of organic recycling. To establish the economic advantages it is of course necessary to know quantitatively what effects recycled organic materials will have on agricultural production in the short and long term. Research needs at present are therefore for some empirical studies of how organic residues are best utilized within specific environments, and within existing agricultural systems, and for some carefully controlled quantitative studies of the effects of organic materials on soil properties and crop production, again in well defined environments.

2. UTILIZATION OF ORGANIC RESIDUES IN SOME FARMING SYSTEMS

2.1 Recurrent Cultivation Systems

Traditional agricultural practice in most tropical regions involves recurrent cultivation systems in which a short period of soil cultivation is followed by a period when the soil is under regenerating natural vegetation (FAO Soils Bulletin No. 24). Alternate husbandry systems, in which a cropping period is alternated with a period when the soil is not cultivated, is maintained under a seeded pasture or planted fallow, are closely similar in principal. The fallow or pasture may be cut or grazed, involving further nutrient removal. Organic matter is removed in the form of harvested parts of plants. If this material is sold "off the farm" it cannot be recycled, but if it is consumed "on the farm" it can be recycled in the form of manures. In general, in these systems, it has been found most satisfactory to allow the replenishment of the soil reserves of organic matter to take place under the fallow or pasture vegetation, while utilizing manures for small vegetable gardens maintained in continuous production.

Needed research in relation to these systems mostly involves quantitative studies of the rates of replenishment of organic matter and nutrient levels by the fallow vegetation, the examination of ranges of species to determine their relative efficiencies in recycling nutrients in different environments, and assessment of the changes in nitrogen status of the soil-vegetation system. An important point to bear in mind is that in a region of low soil fertility, recylcing of organic

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matter and nutrients is likely to do very little more than preserve the low level of fertility. To break out of the low level, it is necessary to identify the factors inhibiting improvements in productivity. This will often mean adding fertilizers to the system. In areas where the fallow vegetation is burnt annually, repeated losses of nitrogen and sulphur occur during the burn, because these elements are converted to gaseous products. Levels of soil nitrogen and sulphur hence tend to be low. If the system of animal production is not viable without burning, and policy is to continue the practice (the "early burn" policy), then methods of contributing these elements economically to the system must be developed. Nitrogen can be obtained by biological fixation, but sulphur will normally have to be added. In industrial areas there is a sufficient contribution from rainfall, but in non-industrial areas it must be added from fertilizers or manures. In Australia, alternate husbandry systems have attained a high degree of efficiency through the development of the 'super and sub' system, in which phosphorus and sulphur are added to the soil as superphosphate, to raise its fertility, and nitrogen is obtained by biological nitrogen fixation in the nodules of the pasture legume subterranean clover. Because the C:N:S:P ratio in soil organic matter is reasonably constant, the level of organic matter in the soil cannot be increased significantly without additions of N, P and S, and the "super and sub" system is successful because all three elements are added.

Quantitative studies of the nutrient cycles involving these elements are therefore essential if the changes in soil fertility in alternate husbandry systems are to be understood, and if the productivity of such systems is to be raised or at least maintained by recycling of organic materials.

Where organic residues and manures are concentrated at a smaller 'garden' rather than returned to the land where they were produced, it is obviously important to evaluate both parts of the system.

Where information is still very scarce is in relation to quantitative detail of rates of organic matter turnover on specific, physically and chemically well defined, soils. The rates of oxidation of soil organic matter and the rates at which nutrients are leached in different stages of the system, also remain to be quantified.

2.2 Continuous Cultivation Systems

If the productivity of soils utilized for continuous cultivation is to be maintained, it is essential that the nutrients removed in crops be replenished, either by additions of fertilizer or by recycling of organic materials. Although it is possible on some soils to maintain high levels of productivity at low levels of soil organic matter, it is much easier to do so if the organic matter is maintained at a relatively high level. Returning all possible organic material to the soil does of course help to do this. Research needs again relate to quantifying the effects of additions on the physical and chemical conditions in the soil, and the relation of these to soil productivity. Again no proper understanding of the effects of recycling organic materials can be obtained without critical, quantitative analysis of the complete production system, in a well defined environment. It then becomes possible to assess the economic viability of the system, with and without recycling of organic materials.

One major advance in recycling of crop residues has been made in recent years. This derives from the development of no-tillage systems for arable crop production. In the temperate zone no-till farming is widely practised in Europe and North America. Weeds are controlled with herbicides, and seeds are directly drilled into the land after harvest. All crop residues are left on the ground and contribute organic matter to the soil surface. In the UK, it is now common practice to burn the straw. With wheat straw this is essential as organic acids toxic to the new seedling can be matter and nutrients is likely to do very little more than preserve the low level of fertility. To break out of the low level, it is necessary to identify the factors inhibiting improvements in productivity. This will often mean adding fertilizers to the system. In areas where the fallow vegetation is burnt annually, repeated losses of nitrogen and sulphur occur during the burn, because these elements are converted to gaseous products. Levels of soil nitrogen and sulphur hence tend to be low. If the system of animal production is not viable without burning, and policy is to continue the practice (the "early burn" policy), then methods of contributing these elements economically to the system must be developed. Nitrogen can be obtained by biological fixation, but sulphur will normally have to be added. In industrial areas there is a sufficient contribution from rainfall, but in non-industrial areas it must be added from fertilizers or manures. In Australia, alternate husbandry systems have attained a high degree of efficiency through the development of the 'super and sub' system, in which phosphorus and sulphur are added to the soil as superphosphate, to raise its fertility, and nitrogen is obtained by biological nitrogen fixation in the nodules of the pasture legume subterranean clover. Because the C:N:S:P ratio in soil organic matter is reasonably constant, the level of organic matter in the soil cannot be increased significantly without additions of N, P and S, and the "super and sub" system is successful because all three elements are added.

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Where information is still very scarce is in relation to quantitative detail of rates of organic matter turnover on specific, physically and chemically well defined, soils. The rates of oxidation of soil organic matter and the rates at which nutrients are leached in different stages of the system, also remain to be quantified.

2.2 Continuous Cultivation Systems

If the productivity of soils utilized for continuous cultivation is to be maintained, it is essential that the nutrients removed in crops be replenished, either by additions of fertilizer or by recycling of organic materials. Although it is possible on some soils to maintain high levels of productivity at low levels of soil organic matter, it is much easier to do so if the organic matter is maintained at a relatively high level. Returning all possible organic material to the soil does of course help to do this. Research needs again relate to quantifying the effects of additions on the physical and chemical conditions in the soil, and the relation of these to soil productivity. Again no proper understanding of the effects of recycling organic materials can be obtained without critical, quantitative analysis of the complete production system, in a well defined environment. It then becomes possible to assess the economic viability of the system, with and without recycling of organic materials.

One major advance in recycling of crop residues has been made in recent years. This derives from the development of no-tillage systems for arable crop production. In the temperate zone no-till farming is widely practised in Europe and North America. Weeds are controlled with herbicides, and seeds are directly drilled into the land after harvest. All crop residues are left on the ground and contribute organic matter to the soil surface. In the UK, it is now common practice to burn the straw. With wheat straw this is essential as organic acids toxic to the new seedling can be

The current research need is therefore for a few experiments on which very detailed records of all factors effecting changes in soil properties and the influence of organic materials on those properties are obtained. Such experiments cannot be conducted except by a team of scientists including soil chemists, physicists and biologists as well as an agronomist, and at least the collaboration of a microclimatologist and a plant pathologist.

These experiments, together with some simpler experiments over a wide range of climatic conditions should enable a much better basis to be obtained for predicting the effects of organic materials on soil properties. The relation between changes in soil properties and changes in crop production is a further complex subject involving management factors, specific crop requirements and climatic conditions, but at least if the soil changes can be predicted, one important aspect relating to changes in crop production is known.

PLANT CHARACTERISTICS IMPORTANT TO ORGANIC RECYCLING

1 Leguminosae

Biological nitrogen fixation is an important aspect of organic recycling and maintenance of soil fertility. The importance of studies of rhizobia and the relative efficiency in fixing nitrogen, and their effectiveness in nodulating legumes has rightly received much attention. However recent work, particularly with the grain legumes, has demonstrated that the plant characteristics, rather than the rhizobial strain, often determines the amount of nitrogen fixed. This is because the rhizobial activity in the nodule is dependent on the supply of energy from the plant. The rate at which energy materials reach the nodule is of course dependent on the photosynthetic activity and the competing demands of development in other parts of the plant. The current research need here is therefore for physiological studies of the legume-rhizobium interaction, requiring close collaboration of plant physiologist and microbiologist, working in a symbiotic relationship similar to that of the legume and rhizobium.

There is also need for further study of the relation between legumes and other crops when they are grown together, grain legumes with cereals, pasture legumes with grasses, and creeping legumes ("live mulches", such as *Desmodium triflorum* and "*Arachis prostratis*").

Grasses

In the past, vigorous grasses have been extensively studied as fallows for regenerating soil fertility. Using elephant grass (*Pennisetum purpureum*) and Guinea grass (*Panicum maximum*) soil organic matter often increases substantially, presumably due to the active nitrogen fixing population living in the rhizosphere and fed by the vigorous growth of the grasses. Aspects of this association between grasses and nitrogen fixation are discussed in several chapters of "Biological Nitrogen Fixation in Farming Systems of the Troics", edited by Drs. Ayanaba and Dart and published this year by Wileys of Chichester. In spite of the favourable effect of these grasses on soil conditions, they have not been incorporated into viable farming systems. The research need here is to find grass species which are readily utilizable for feed for animals, which are easily established, and easily supplanted by food crops. For much of Africa they must also show a significant advantage over natural fallows in terms of their use for grazing and effects on soil fertility.

4.3 Trees

Trees are the great recyclers. Where trees are grown as commercial crops they will usually maintain soil fertility, through recycling of nutrients within the closed system. Where fertility is initially low it may be necessary to raise productivity through introduction of fertilizers during development of the tree stand, or when significant quantities of nutrients are removed in harvested parts. Advantage of the recycling activity of trees is well used in systems of agri-silviculture. Critical studies of the relative advantages of different tree species in relation to their effects on soil fertility, as well as their value as producers of wood, are needed. Further research needs exist in relation to the way in which trees may best be allied with agriculture. The best utilization of their recycling potential may not be to grow them in alternation with food crops, but to place them in appropriate positions on the landscape, so that nutrients are still recycled from deeper soil layers, while continuous cultivation is possible in intervening or adjacent areas. Maintenance of organic matter might require utilization of loppings or litter from the trees on the cultivated areas. With leguminous trees the leaves would of course provide a source of nitrogen, and litter and leaves the source of nutrients. As far as nutrients other than nitrogen and sulphur are concerned, transport problems could be minimized by burning the litter and carrying the ash to the fields. The system then starts to resemble the 'citimene' systems of Zambia, except that the trees would be selected for their efficiency in recycling, and deliberately planted in the most suitable situations. Normally however it will be desirable to conserve most of the leafy material from the trees, to take advantage of the nitrogen and sulphur as well as other nutrients contained.

4.4 Water plants

Water lettuce and water cabbage are often decried as a major threat to waterways. However they offer useful sources of organic materials, and collect nutrients leached from soils into waterways. They have been used successfully in various parts of the world as composting materials and mulches. Thus there is a research need to examine the various problems associated with the collection and use of these materials.

5. OTHER RESEARCH NEEDS

In the report of the Expert Consultation on the use of "Organic Material as Fertilizers" (FAO Soils Bulletin 27), a concise series of recommendations were given for Short Term and Long Term research, and a set of guidelines were prepared. Much of what has been stated in this paper is covered by these recommendations and guidelines, and by the more extensive compilation of areas of study related to the topic prepared by Professor B.R. Nagar and presented in the same report. These statements indicate many other areas where research needs exist in relation to organic recycling in agriculture. In particular, work is needed on the use of animal manures, sewage sludges and town wastes, both in relation to their effects on soils, but perhaps more importantly in relation to their effects on crop production. The importance of studies on the relation between the use of these materials to the spread of human disease organisms must also be stressed.

Paper 18

ORGANIC RECYCLING IN ASIAN AGRICULTURE

A. Singh and V. Balasubramanian [1]

1. INTRODUCTION

There is a growing awareness everywhere regarding the finite nature of resources in our planet earth, and the need to conserve the fast dwindling ones for our extended use. Ultimately the resource economy must be based on the use of the sun's energy and the effective recycling of renewable resources.

Land in Asia has supported a high level of permanent and continuous cropping for several centuries and this has been possible because of the efficient use of resources. Until recently, waste recycling and use of manures was very common in many Asian countries, but due to the free availability of fertilizers at relatively cheap prices during the sixties and early seventies, interest in the use of organic materials as fertilizers has dwindled. However, the sudden rise in the price of chemical fertilizers since 1973, as a result of the steep hike in petroleum prices, has profoundly affected agricultural production, particularly that of developing countries. The "green revolution" based on heavy fertilizer use turned out to be a farce because of fertilizer shortage and high prices (Burnett 1975). In most Asian countries, fertilizers are expensive because they are imported and the money spent on fertilizers represents almost half the cost of farming. Extensive use of organic manures, with a minimum of chemical fertilizers, will go a long way in reducing the cost of purchasing fertilizers, and improving soil fertility and crop production.

In proper perspective, wastes such as sewage, constitute one of the most readily available resources exploitable simultaneously for economic development and improvement of public health. Waste recycling not only helps in the abatement of environmental pollution but also enhances the availability of nutrients for crop production (Da Silva et al 1976).

The scope for the use of organic wastes as manures is large in Asia where farming is only slightly modernized. The cost of production of organic manures is quite low due to the availability of cheap labour. The need for labour-intensive, land-saving practices is high due to the limited land supply, and the exorbitant cost of mineral fertilizers.

The total amount of waste produced in developing countries contains about 130 million tonnes of NPK nutrients and this represents about eight times the amount of nutrients consumed in the form of mineral fertilizers (13.2 million tonnes of NPK). This indicates the technical scope for the use of organic wastes as nutrient sources in agriculture and animal husbandry (Duncan 1975). Recycling of organic wastes in an integrated scheme of crop - animal - fish and man is necessary to solve the problem of acute food and feed shortage prevalent in developing countries (Ranjhan 1977). This report describes how various organic wastes are utilized in Asian agriculture and how they can be recycled to derive maximum use for human beings.

2. NUTRIENT AND BIOMASS FLOW IN ORGANIC RECYCLING

As most of the plant nutrients are needed both by animals and human beings, a continuous flow of these takes place from soil to plants, from plants to animals and/or man, and from animals to man (Fig. 1). The return flow of these nutrients from plants, animals and man to soil takes place via their wastes and in this process an uncontrolled cycling of these nutrients goes on in nature. Solid lines in

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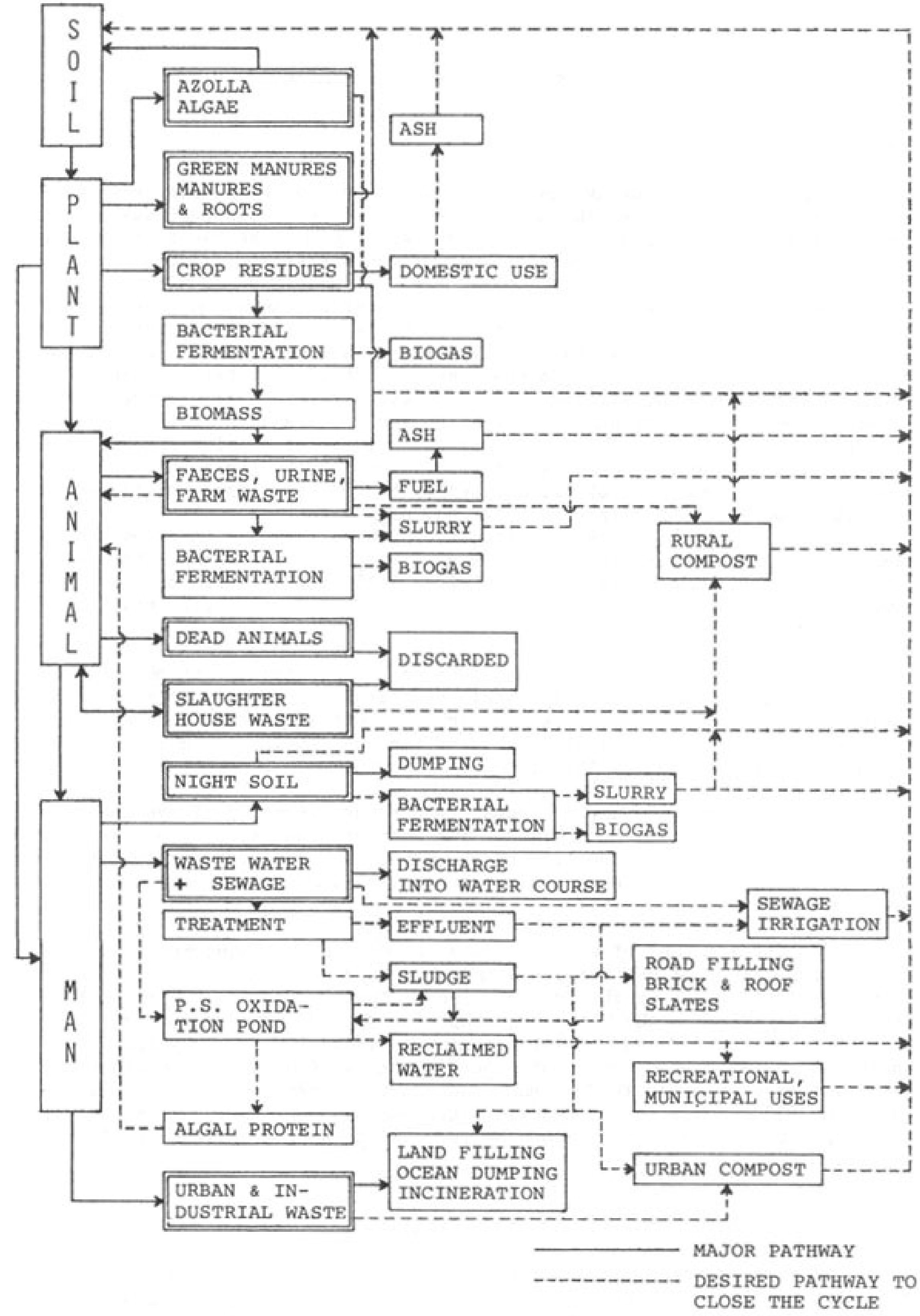

FIG. 1 ORGANIC RECYCLING IN AGRICULTURE

Fig. 1 represent the major pathways of nutrient flow in the present system of waste recycling in which enormous losses and leakages of nutrients and biomass take place; the cycle is not fully complete. Thus only a partial return of humus and nutrients to the soil is effected in the present system. Indefinite continuation of this system will in due course deplete our resources, destroy our soils and disrupt our environment.

Dotted lines represent the routes to improve resource utilization and to ensure effective recycling of nutrients and biomass. Crop residues, dung, night-soil and other biodegradable wastes can be recycled through a biogas system that achieves fuel energy as well as good quality manure and animal feed concentrates. Biogas plants can be integrated into a symbiotic system with aquaculture, agriculture and small scale industries, as pointed out by Da Silva et al (1976). When sewage and other waste waters are treated in industrial plants, effluent and sludge are produced. Sludge can be used for compost making, road filling, manufacture of bricks and roof-slates, and by direct application on land. Raw or treated sewage, if used for irrigation, supplies both water and nutrients to crops. Sewage or effluents can be further treated in photosynthetic (PS) oxidation ponds which yield valuable protein for use as animal feed concentrate and purified water for municipal, recreational, agricultural and industrial uses. Slaughter house, urban and industrial wastes can be composted and used as manure. Other examples of valuable products obtained from various waste used as raw materials can be found in Table 1 taken from Da Silva et al (1976). These authors point out that the already successful cattle-fish-crops cyclical projects developed in India and the Fiji Islands could serve as useful prototype models for streamlining certain rural farming systems in other developing countries.

Only recently there is a world-wide realization that animal and other organic wastes could be utilized most effectively and feasibly through microbial fermentation which yields food or feed from uncoventional sources independent of land use and climatic conditions (Ranjhan 1977). Possible ways of animal waste recycling through microbiological, physical and chemical processes for increased animal production are shown in Fig. 2. Eventually, the wastes are going to be recycled back to human beings as human food resources in the form of animal protein - milk and meat. Also microbes grown on wastes would be used as non-conventional protein food, single cell protein (SCP) for human consumption. The processed wastes, when used as animal feed, would also spare the otherwise limited food resources (grains and vegetable protein) for human use (Ranjhan 1977).

Cellulose forms the principal constitutent of all organic wastes. Its world-wide production has been estimated at about 100 thousand million tonnes per annum (Mandles et al 1974) and most of it is usually wasted. It is possible to get essential protein from cellulose by proper treatments as shown in Fig. 3. Recently suggested mixed microflora (Calvert 1974; Japanese Patent 1976; Anon 1974) is said to attack organic wastes effectively because of the presence of organisms producing cellulolytic and lignolytic enzyme systems (Ranjhan 1977). Cellulose may be utilized in many ways (Fig. 3) once it is degraded.

On the whole, organic wastes are fairly rich sources of carbohydrate, protein and minerals which are required for both the plant and animal kingdom and form a suitable substrate for microbial fermentation. These organic wastes, whatever the sources, need to be transformed into products of utility. Most of these can be routed through different channels (Figs. 1 and 2) and the final residue can go to land as organic fertilizer (Ranjhan 1977).

These recycling projects are described in ensuing chapters. Attempts have been made to point out the missing links in the present waste recycling process and to mention the impressive rewards that can be obtained by efficient waste management.

Table 1 A FEW EXAMPLES OF FOOD AND OTHER PRODUCTS OBTAINED AS A RESULT OF MICROBIAL ACTION ON NATURAL AND INDUSTRIAL WASTES (Da Silva et al 1976)

Country	Products obtained	Raw materials used	Reactive organisms
Chile	Microbial protein	Fruit peels, papaya wastes	Yeast
Egypt	Microbial protein	Bagasse, pith, rice hulls, distillery slops	Candida utilis, C. tropicalis
Guatemala	Animal feeds, enzymes	Bagasse, sugar filter muds, cotton cakes; municipal wastes	Yeasts, bacteria
India	Irrigation water, fish culture medium, organic acidulants, enzymes	Domestic and industrial wastes, molasses, seaweed, cellulosic materials	-
Indonesia	Ontjom, tempe mata kedele	Peanut presscake, hypocotyl of soyabean seed	Neurospora sp., Rhizopus sp.
Israel	Fodder yeasts	Citrus peels, cannery wastes	C. tropicalis
Malaysia	Fish sauce, poultry feed, B-vitamins, glutamates	Fish wastes, tapioca rejects, rubber processing, palm oil effluents	Bacteria, Chlorella sp.
Nigeria	Single cell protein, compost, poultry feed	Cassava wastes, rice straw and hulls	-
Pakistan	Organic accidulants, enzymes	Seaweed, molasses, cellulosic wastes	-
Philippines	Vinegar, nata di coco	Water from copra extraction	Torula sp. Leuconostoc sp.
Senegal	Compost, animal feeds	Millet, sorghum and groundnut wastes	-
Sri Lanka	Vinegar, organic acidulants	Copra extraction waters, cellulosic wastes, molasses	Torula sp.
Thailand	Single-cell protein, fish sauce, yeast, soft drinks	Municipal wastes, trash, fish and fish rejects; coconut water, cassava and vegetable wastes	Torula sp., Chlorella sp.

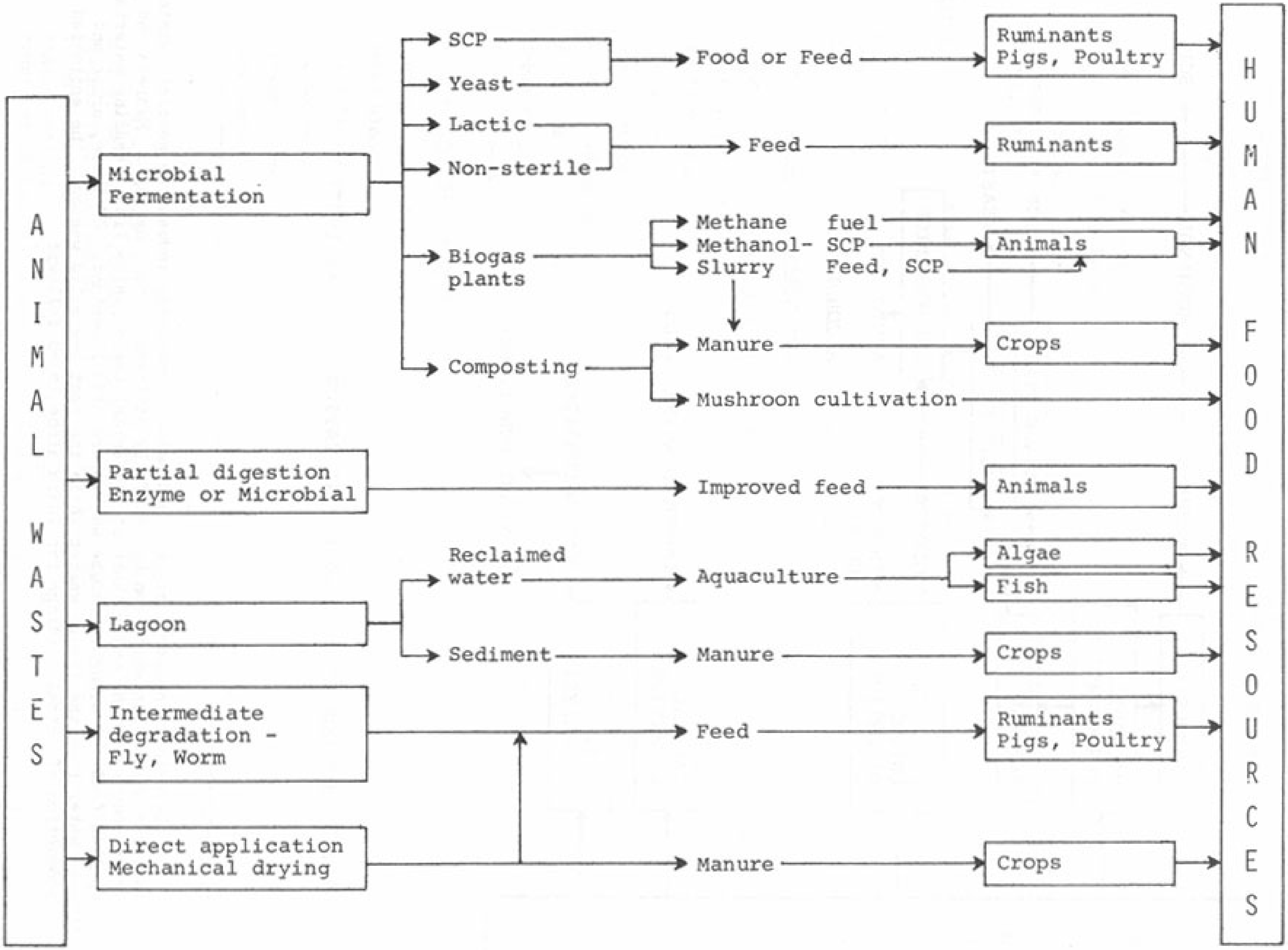

FIG. 2 POSSIBLE WAYS OF RECYCLING ANIMAL WASTES (RANJHAN 1977)

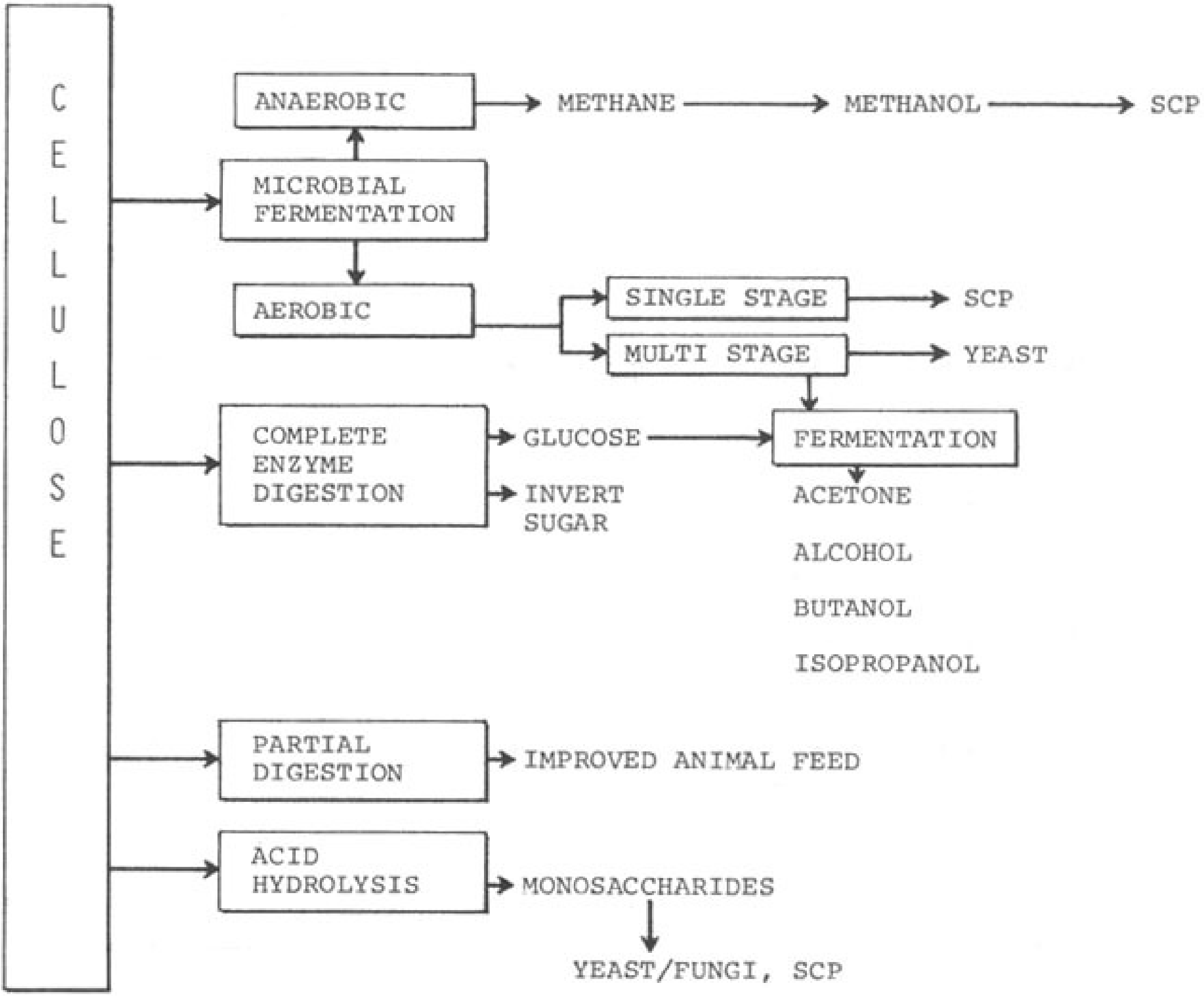

FIG. 3 METHODS OF CELLULOSE UTILIZATION (RANJHAN 1977)

3. ANIMAL WASTES

Livestock, poultry, piggery and animal processing industries generate wastes in large quantities which can be gainfully utilized in various ways. Excreta and urine constitute the major share of the animal wastes, while litter/bedding materials, spilled feed and slaughter house wastes are also important. Of these, urine and wash water form the liquid wastes while the rest are solid wastes. The estimated production of animal voidings for India alone is as follows:

Cattle dung	– 1 335	million	tonnes	NCAER 1965
Cattle urine	370	"	"	Garg et al 1971
Sheep) Goat) excreta	30	"	"	Ranjhan 1977
Sheep) Goat) urine	15	"	"	
Swine excreta	6			
Poultry droppings –	0.06	"	"	

The wastes are rich in nutrients (Table 2) and thus could be utilized either as manure or as unconventional animal feed sources for livestock, poultry and fish (Fig. 4).

Table 2

MEAN NUTRIENT CONTENT OF ANIMAL AND HUMAN WASTES
(VALUES IN PERCENT DRY WEIGHT BASIS)

Waste	N	P_2O_5	K_2O	CaO
Faeces and Other Wastes				
Dung	1.8	1.6	1.0	–
Fresh night soil	4.0	3.5	1.3	–
Poultry manure	4.0	2.3	2.3	4.0
Cattle manure	0.7	0.3	0.9	2.5
Sheep manure	1.4	0.2	1.0	3.5
Sewage sludge, dried	2.0	2.0	–	2.5
Sewage sludge, activated	6.0	3.0	0.5	2.5
Urban compost	1.0	1.0	1.0	5.5
Rural compost	0.8	0.5	0.5	–
Animal Processing Wastes				
Hoof and horn meal	14.0	–	1.0	2.5
Dried blood	10.0	2.0	1.0	0.5
Dried fish scrap	8.0	6.0	–	8.5
Raw bone-meal	4.0	22.0	–	31.5
Steamed bone-meal	2.5	26.0	–	33.0
Wool waste	3.5	0.5	2.0	0.5

Sources: FAO 1975; FAO 1962; Kanwar and Chopra 1959; and Singh 1975.

Blood, bone, waste meat, hair, horn, hoof, feather, fish scale, etc. are some of the animal wastes generated in meat, bird and fish processing units; waste leather from the tanning industry can also be included here. These wastes are rich in nutrients and can form a useful supplementary source for poultry, swine and cattle rations (Ranjhan 1977). There are not many meat packing plants in developing countries of Asia to provide these wastes in bulk for commercial exploitation.

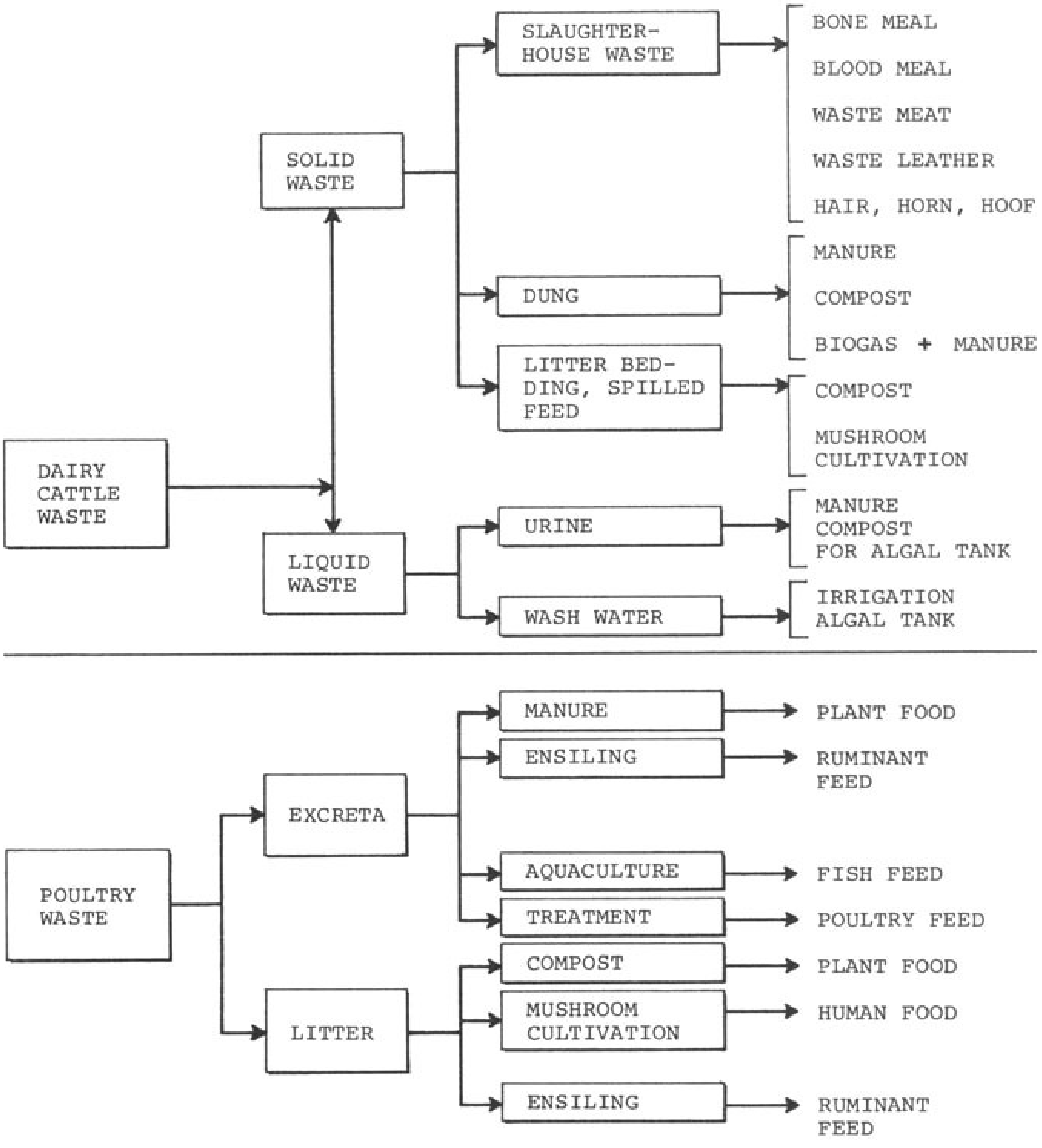

FIG. 4 EFFICIENT UTILIZATION OF DAIRY CATTLE AND POULTY WASTES (RANJHAN 1977)

Slaughter houses do almost all the jobs of the meat packing plant but no arrangements exist to conserve the waste. Similarly, in poultry processing plants, discarded wastes could be properly processed and utilized as an animal feed constitutent; and the remainder diverted to soil as manure. The nutrient content of slaughter houses and animal processing wastes is given in Table 2.

3.1 Present Methods of Animal Waste Utilization

i. Manure

Conventionally, most animal wastes are used as manure for crops while some quantity of dung is burnt as domestic fuel. Since mixed farming is common in Asia, use of animal manure for crop production is very much facilitated. The amount of manure production per animal per year is roughly 8 tonnes for cattle, 2 tonnes for pigs and horses, 300 kg for sheep and goats and 12 kg for fowls (Burnett 1975).

Although farmyard manure is the most commonly used organic fertilizer in Asian agriculture, the production level of cattle manure is quite low vis-a-vis potential and its quality is very poor (Table 2). This is largely due to:

a. failure to utilize all the vegetable refuse and cattle dung available on the farm;

b. burning of dried dung as domestic fuel;

c. the complete neglect of cattle urine in the collection procedure; and

d. the defective method of preparation in exposed heaps which leads to nutrient losses through drying and volatilization in summer and leaching and runoff in the wet season and improper decomposition (FAO 1975).

The provision of impervious flooring for cattle sheds will facilitate urine collection, while proper processing in pits or covered heaps will minimize nutrient losses.

In certain areas, there is close cooperation between pastoralists and cultivators and the animal manure is exchanged for food or cash.

ii. Fuel

Use of dried dung as fuel is a common practice in India, Pakistan, Bangladesh, Sri Lanka and other Asian countries. Burning of the dung not only deprives the soil of organic matter and nutrients for improving soil fertility, but also acts as a great hindrance in fully exploiting the energy content of dung. As much as one-third to one-half of the dung produced in India is burnt for cooking purposes; dung cakes are even used for baking bricks.

In order to dissuade farmers from using cow-dung for fuel, alternate energy sources (wood, subsidized kerosine, biogas, solar energy) should be provided in rural areas.

The indiscriminate cutting of trees for fuel causes soil and water erosion and disturbs the natural ecosystem. Mass planting of quick-growing species of trees will be of some help to meet the rural energy requirement. It is reported that in China trees have been planted everywhere along road sides, canal banks, railway lines and on hillsides (Anon 1976). A list of fast growing trees adaptable to adverse soil and climatic conditions is given in Table 3. Established tree groves will also act as wind-breaks, reduce soil erosion, check desertification and provide leaf-litter for composting. In

Table 3 A LIST OF FAST-GROWING TREES AND THEIR ADAPTATION TO SOIL CLIMATIC ZONES

Name	Suitable Soil-climatic Zone
Acacia arabica	Alluvial plains and dry zones
Acacia auriculiformis	Wet and coastal zones
Acacia catechu	Dry zone
Albizzia lebbek	Dry zone
Bambusa spp	Dry and wet zones
Cassia siamea	Dry and coastal zones
Casuarina equisetifolia	Dry and wet zones
Dalbergia sissoo	Alluvial plains
Dendrocalamus strictus	Dry and wet zones
Eucalyptus spp	Dry, wet and coastal zones
Grewia oppositifolia	Semi-dry zone
Margosa indica	Dry and wet zones
Morus alba	Alluvial and dry zones
Pongamia glabra	Alluvial and coastal zones
Quercus incana	Dry zone
Tamarix articulata	Dry zone

addition, if the present research on solar energy comes up with cheap and efficient solar cookers, it will aid in a great way to solve the energy crisis problems. Attempts are being made in this direction at the Central Arid Zone Research Institute, Jodhpur, India (Garg and Thanvi 1977).

iii. Biogas and Manure

Animal wastes can also be processed through anaerobic fermentation in biogas plants which yield methane gas for cooking and other purposes as well as manure. The spent slurry left over after gas production is rich in humus and nutrients and forms a good quality manure. Details of design, operation, maintenance and cost-benefit analysis are discussed in Section 8 of this paper.

Biogas plants are slowly gaining popularity in India in spite of high initial cost for installation and up to 1975 more than 16 000 plants had been installed by various agencies. The Government of India subsidizes the installation cost up to 25 percent. The target is to have 100 000 biogas plants in India by the end of Fifth Five Year Plan period. Reports indicate that there are about 29 000 biogas plants operating in the Republic of Korea (Da Silva et al 1976) and 300 000 in China (Anon 1976).

3.2 Other Proposed Ways of Animal Waste Recycling

Efficient recycling of animal wastes are set out in Figs. 2 and 3 (Ranjhan 1977).

3.2.1 Protein enrichment of animal wastes for refeeding

Attempts are continuously made to evaluate various processes - physical, chemical and microbiological - to upgrade wastes to acceptable animal feed stuffs.

i. Cattle wastes

Dried cattle manure has been shown to serve as feed for pigs and poultry, substituting 5 - 15% of the total ration (Hammond 1942) and for ewes and growing heifers (Smith et al 1971, 1974). With relatively simple machinery and chemical processing, cattle manure can be sterilized, washed, dried and fermented to produce odour-free feed stuff (Smith 1969; Anthony 1970; Anon 1974). The CERECO process developed by Ward et al (1975) produces three fractions from feedlot manure: a high fibre silage, a dried protein product and a high ash residue. "Wastelage", developed by Anthony (1969) and Bandel and Anthony (1969), is nothing but an ensiled mixture of 57% cattle manure and 43% ground hay. This product has the same characteristics as the conventional silage and it is readily consumed and utilized by cattle without any adverse effect on animal health. Yeck et al (1975) have reviewed the recovery of nutrients from animal wastes and presented an overview of existing options and potential for their use in feed.

ii. Pig Waste

Dried swine faeces (Orr 1973; Diggs et al 1975), oxidation ditch liquor (Orr 1973) and oxidation ditch mixed liquor (Harmon et al 1971 and 1972; Harmon and Day 1975) have been tested as feed ingredients. While ruminants can use more simple products like urea and uric acid, swine must have preformed amino acids in their diet. Harmon and Day (1975) have successfully developed a system by which swine waste can be biologically enhanced forming SCP in a near odour-free aerobic environment. In this system, the amino acids have to be substituted in the basal diet as the oxidation ditch liquor provides mainly vitamins and minerals. A constant volume of liquid should be maintained in the ditch by adding water and the ditch may be emptied every 2-3 years when the ash content becomes high.

iii. Poultry Waste

Broiler litter contains more than 28% crude protein, 59.8% total digestible nutrients and 2 440 K Cal of digestible energy per kg (Bhattacharya and Fontenot 1966). These values compare well with those of a roughage such as alfalfa hay. Poultry wastes are good sources of Ca and P and have been successfully ensiled with corn forage for use as sheep feed (Fontenot and Webb 1974), ground corn molasses and Lactobacillus acidophillus for ruminant feed (Vezey and Dobbins Jr. 1975), and with green maize and molasses for farm animals (Pathak et al 1975 and 1976). Silage mix containing 20% each of poultry litter, molasses and green maize and 40% rice straw has been shown to be an excellent feed for adult cattle (Neog 1976). Fontenot and Webb (1975) found that the addition of broiler litter to corn forage or high moisture corn grain improved the palatability and digestibility of the ensiled feed. Dehydrated poultry waste can be an economic feed for poultry mainly as a source of energy, amino acids and minerals (Ca and P). It has been shown in India that poultry droppings form an acceptable feed for cattle and buffalo after drying or after autoclaving, drying and milling (Jayal and Misra 1971; Pathak et al 1975).

Health hazards involved in such systems of recycling animal wastes will be discussed further.

3.2.2 Animal waste as substrate for SCP production

Certain specialized systems utilize the N from the waste for production of SCP suitable for human food or livestock feed. These systems include algae, yeasts, fungi, and bacteria and mixed cultures. Certain invertebrates are also considered as potential producers of SCP from wastes. The sophisticated technology for SCP production may not suit developing countries due to the high cost of investment in machinery and lack of skilled manpower.

3.2.3 Algae

The commonly used species of algae are Chlorella, Spirulina, and Scendesmus. It is an established practice to use algae in sewage treatment plants where they serve as a source of O_2 for aerobic digestion of organic materials. Reclaimed water and algal protein are the two by-products of this system. But the use of algae for protein production from animal wastes is of recent origin. The projected global capacity of the mass culture system in 1989, is estimated to be 10^{15} litres which could supply enough feed for the entire livestock to take care of the total world protein need (Krauss 1962; Oswald and Glucke 1968; and Priestley 1976).

Duncan et al (1969, 1971) developed a system in which the caged poultry layer waste is flushed into the sedimentation tank, supernatent from this tank is pumped directly to an algae pond and the sediment is pumped to an anaerobic digester for methane production. Methane gas is used to heat the digester. Effluent from the anaerobic digester is also pumped into the algae pond. After algae separation, the water is recycled in the system. The algal yield was found to be 11-15 t dry matter/ha/year.

In a similar system, Milner et al (1975) used swine wastes for algal production. The projected yields of crude protein have been shown to be 55 t/ha/year. Thus the use of algae to convert manure to usable feed-grade protein appears to have the most promising future (Calvert 1974 and 1976). The amount of waste N converted to protein is as great as or greater than in any other known system. The main drawbacks of this system are:

i. large space requirement for algal ponds;

ii. difficulties in separation of algae from substrate;

iii. high cost of establishment; and

iv. climatic and topographic limitation on pond function.

A technical breakthrough is still needed to overcome the above problems and to make it applicable for cheap and safe food/feed production from algae.

The Indian Council of Agriculture Research, New Delhi, has set up an All India Coordinated Project to examine algal protein production in the country.

4. CROP RESIDUES, RURAL COMPOST, SILT AND PEAT

4.1 Crop Residues

Harvest residues (straws, stover, haulms) and process wastes (groundnut shell, rice husks, oil cakes) are the two major components of crop residues. The nutrient content of crop residues is provided in Table 4. These residues can be directly applied to the field and ploughed in or used for fuel, animal feed, compost and other domestic purposes (fencing and roofing). Wheat and rice straw, legume tops and oil cakes are popular cattle feeds in most parts of Asia. Spoiled grains and chaff are fed to fowls and ducks. The wastes from animals in turn are collected, processed as farm manure or compost and applied to soils. Since there is severe competition for crop residue for various purposes, only a small percentage of it is used as organic manures in fields. For instance, rice straw in Japan is used as litter for domestic animals, feed stuff for livestock, soil ameliorating or mulching material for horticultural crops and as raw material for some cottage industries; rice straw is also directly ploughed into the soil (Egawa 1975).

Table 4 NUTRIENT CONTENT OF CROP RESIDUES

Waste	N	P	K	Ca	Mg	S
Harvest Refuse						
Rice straw	0.48	0.13	1.33	0.20	0.11	-
Wheat straw	0.42	0.12	1.72	0.27	0.15	0.12
Millet stover	0.65	0.09	1.82	0.35	0.23	0.15
Sorghum stover	0.58	0.10	1.51	0.21	0.13	0.10
Maize stover	0.70	0.14	1.43	0.36	0.11	0.12
Groundnut haulms	1.40	0.21	1.80	0.90	0.50	0.18
Cowpea stems	1.07	0.14	2.54	0.69	0.25	-
Cotton stalks	1.33	0.27	2.35	1.27	0.25	-
Process Wastes						
Cotton-seed meal	7.50	1.15	1.20	0.35	0.35	-
Groundnut cake	7.80	0.58	1.05	-	-	-
Castor meal	5.70	0.92	0.80	-	-	-
Toria Cake	5.60	1.25	0.80	-	-	-
Groundnut shell	1.00	0.06	0.90	0.25	0.10	0.10
Wood ash	-	0.65	4.00	21.50	-	-
Cannery waste	1.20	-	-	-	-	-
Distillery waste	0.50	0.90	30.00	12.20	3.50	5.00

Sources: Authors' analytical data unpublished; Charreau 1974; and Kanwar and Chopra 1959.

In Asia, crop residues are therefore mostly recycled through animals rather than by direct incorporation into the soil.

Cereal straw can readily undergo anaerobic bacterial fermentation to produce a biogas consisting of 70% methane (by volume) and 30% CO_2. The heating value of this gas is 25.9 MJ/m^3 (25.5 MJ/kg) compared to a value of 37-41 MJ/m^3 for natural gas. One tonne of dry straw yields 0.22 t of methane gas.

The solid residue left over after biogas production is rich in protein (12% digestible or 30% crude protein); it also contains vitamins (B_{12}) and liquid material. Such a product can be used as an animal feed for ruminants (McCann and

Saddler 1976). Further work is needed to find the relative profitability of biogas production from straw as well as from dung or night soil. If straw based methane production is found more profitable, it can be popularized in rice belts of Asia (Japan and South East Asian countries).

4.2 Rural Compost

The major sources of rural waste are crop residues, domestic solid wastes, green or dried leaf litters, weeds, wild grasses, water hyacinth, saw dust, wood shavings, groundnut shell, rice husk and others. Systematic collection and decomposition of these wastes in pits or piles is called composting; fresh manure or night soil is sometimes added to vegetable wastes to activate the natural biochemical process. Vegetable materials are piled in layers, each of which is covered with a thin layer of fresh manure. The piles are 5-10 m long, 3-4 m wide and 1½ m high. The compost can be enriched with lime, natural phosphates, N and/or K fertilizers.

Rice straw compost has been very popular in Japan (Egawa 1975) and South East Asian countries. In India, high quality compost is prepared under the Indore or Bangalore methods (Garg et al 1971). Compost is mainly used for horticultural and cash crops. The heavy labour requirement for processing and transport has caused a decline in compost preparation in industrialized countries like Japan where agricultural labour is scarce and expensive and the farming is mechanized to a great extent (Egawa 1975). Direct incorporation of straw by tractor ploughing is becoming more and more popular in Japan. Since composting needs water for decomposition, it cannot be extensively practised in dry areas.

A travel report on China (Anon 1976) indicates that Chinese use all waste material, both urban and rural, crop, human and animal wastes, weeds, and even some leguminous and other plants specially grown on the banks of the rice fields for composting. A large number of people including some from educational institutions in the agricultural areas are engaged in transporting (mostly in push carts) and spreading of composts in the fields. The goal is that every field should receive, depending on the crop, at least 10 to 30 t/ha of compost. The normal application rates are 75-150 t/ha for rice, 100 t/ha for groundnuts, and 50 t/ha each of compost and silt for sugarcane. Another report (Hauck 1977) reveals that, on an average, Chinese supply 70% of the plant nutrient requirement through organic manures and 30% from mineral fertilizers.

Aquatic weeds like water-hyacinth are abundant in canals, rivers and tanks in Asia. Water-hyacinth contains 2.1% N, 1.1% P_2O_5, 2.5% K_2O, 3.9% CaO and 27.3% C (Ranjhan 1977). Bulk for bulk hyacinth compost is twice as rich as town compost and four times as rich as farmyard manure. It is suitable for jute and rice fields, for vegetable gardening, fruit growing and possibly for mushroom cultivation. Water-hyacinth eradication through composting is not only practical but also remunerative. Trials are also being undertaken to exploit the nutritional potential of water-hyacinth for animal feeding (Wobuerton and McDonald 1976). Although aquatic plants are considered as troublesome weeds in most parts of the world, Chinese people cultivate aquatic plants like Eichhornia, Alternanthera and Pistia for later use in animal feeding and composting (Hauck 1977).

The cultivated areas in rivers and lakes are controlled by borderlines so that traffic and fish cultures are not affected. On an average, 220 to 250 t/ha/year of aquatic plants are harvested. Aquatic plants are mixed with silt in the preparation of compost.

There are so many other farm weeds which are rich in nutrients. For instance, Chenopodium album (L) is a major weed of winter crops, specially wheat. In many parts of India, this weed is removed by hand and is thrown away as a waste. As shown in Table 5, Chenopodium is rich in N, K, Ca and Mg and can be used as greens for human consumption or as a potential source of minerals for the animal population

(Shahi 1977). Other farm weeds that are not fit for human or animal consumption can be composted before flowering and used as manure (Shukla and Vimal 1967).

Table 5 MINERAL COMPOSITION OF *CHENOPODIUM ALBUM* (L)
AT DIFFERENT GROWTH STAGES (Shahi 1977)

Constituent	Days after planting			
	45	85	125	143
N	6.30	3.80	2.47	2.20
P	0.60	0.43	0.42	0.38
K	0.10	6.05	3.55	3.35
Ca	2.25	1.45	1.25	1.08
Mg	1.65	1.27	0.99	0.86
Fe	-	-	-	0.038
Mn	-	-	-	0.148

4.3 Silt

Fine soil particles and nutrients carried in runoff waters end up as silt in tanks, lakes, ponds and dams. If these water bodies carry aquatic vegetation (water-hyacinth, lotus, lily, etc.) then a lot of organic matter is added to the silt as the vegetation rots in due course. When the water level comes down or when the ponds dry up in summer months, the nutrient rich silt is dug up and applied directly to the fields or composted with vegetable waste. This practice not only reverses soil erosion by adding clay, silt and nutrients to the field, but also helps to desilt and deepen the rivers and stillwater bodies for efficient storage of water in the rainy season. The extra labour available during the off-season can be constructively utilized for desilting purposes.

4.4 Peat

It is not much used as an organic fertilizers; it is mainly used as a medium to support legume inoculation bacteria. The reserve of peat is quite low in Asia.

5. GREEN MANURES, LEGUMES, AZOLLA, ALGAE AND BACTERIA

5.1 Green Manures

At one time or another green manures have been used to maintain soil fertility in the agricultural history of many countries. In the flooded rice cultivation of Asia it has been a common practice to raise a green manure crop (usually a legume) at the beginning of the rainy season, plough it in when the crop is 6-7 weeks old and allow it to decompose for another 3-4 weeks prior to the transplanting of rice seedlings. Thus 10 weeks is needed to practice green manuring in rice culture and farmers may some times lose the best part of the rainy season before planting the main crop of rice. Green manure is an efficient way to maintain soil fertility where there is no livestock husbandry or mixed farming and where the cropping intensity is very low. The popularity of green manuring has been waning in recent years due to:

i. increased intensity of cultivation with more than one crop every year;

ii. no immediate (cash or kind) income for green manures;

iii. the need for water to raise and decompose green manure crops;

iv. the short-lived nature of green manure effects in tropical soils; and

v. the lack of addition of any new nutrients (except N) from external sources to the soil.

In traditional Chinese agriculture green manure is said to have been very little used because almost any crop was too valuable to plough into the soil before it had been consumed by man or animal (Allison 1973).

Green leaf manuring is the practice of collecting green leaves and tender stems from various vegetative sources (live fences, wind-break or road-side trees, forests, etc.) and applying them to the field 4-6 weeks prior to planting the main crop. In this case there is a true addition of nutrients to the cultivated field and only four to six weeks is needed for decomposition of added green matter. Quick growing shrubs (Glyricidia and Sesbania) are especially planted on field bunds for green leaf production.

5.2 Legumes

In the context of today's intensive agriculture, the practice of green manuring cannot be afforded but certainly one fodder or grain legume can be grown in multiple cropping sequence involving two or three crops a year. Characteristics and N content of some selected green manures and various legumes are given in Table 6. Fodder or grain legume crops yield some cash or kind return to the farmer as well as provide green matter to plough into the soil. In certain places, legumes (Phaseolus trilobus) are sown in a standing rice crop about a week before harvesting; this crop utilizes the residual moisture left over after rice harvest and yields some grains and green matter. If the seeds are not intended to be collected, then animals may be allowed to graze the land and the crop can thus be utilized as a green fodder. Such practices do not interfere with the regular cultivation of main crops. The cultivation of crops mainly to be used as fodder is practised only to a limited extent in Asia. Grain legumes are normally planted in rotation and mixed cropping in growing and established orchards, and with plantation crops in multilayer cropping.

Lack of knowledge in the use of rhizobia, the commercialization of really bad inoculants due to absence of quality control and the lack of proper support media for inoculants have to be solved in order to make a breakthrough in biological N fixation in developing countries (Batthyany 1975). A simple methodology of preparation of bacterial inoculum for legumes has been developed in China which, for practical purposes, is good enough to replace the cumbersome and costly method carried out in special laboratories (Hauck 1977). N fixation by selected legumes is furnished in Table 7.

5.3 Azolla

The fern Azolla is found in shallow ponds, ditches and channels containing stagnant water mostly in the winter season when the temperature is low in tropical Asia. The N-fixing blue-green alga Anabaena azolla is always found in the cavities of dorsal leaves as a symbiont which fixes atmospheric N necessary for the growth of the plant. Azolla contains 4-6% N and is also rich in P. It is frequently attacked by the larvae of Lepidopterous and Dipterous insects which should be controlled by insecticide (furadon) application. The optimum pH for Azolla is 6 to 7; its growth rate is slow in high pH soils and zero in very acid soils (pH 3.8) as observed by Singh (1977).

Table 6 CHARACTERISTICS OF SOME LEGUMES SUITABLE FOR USE AS GREEN MANURE AND/OR FODDER LEGUME

Name	Plant character	Resistance to drought	Resistance to water logging	N %
Clitoria ternata	A; E	R	-	2.8
Crotalaria anagyroides	P; E	SS	-	3.9
Crotalaria juncea	A; E; QG	R	S	2.0
Crotalaria striata	A; SP; SG	SS	-	3.9
Crotalaria usarmoensis	A; E; SG	S	-	5.3
Cymopsis psoraloides	A; E	RR	S	4.3
Dolichos biflorus	A; E	-	-	1.8
Dolichos lablab	A; SP	S	R	2.1
Desmodium diffusum	A; E	-	-	2.0
Indigofera anil	A; E	R	-	3.7
Melilotus parviflora	A; E	RR	-	2.6
Phaseolus trilobus	A; E	-	-	1.9
Phaseolus aureus	A; E; QG	R	S	2.1
Sesbania aculeata	A; ET; QG	R	RR	2.8
Sesbania sericea	A; ET; SG	R	RR	2.2
Sesbania speciosa	A; ET; SG	R	RR	2.9
Tephrosis purpurea	A; E; SG	-	-	3.7
Vigna unguiculata	A; E; QG	R	S	2.5

Plant character - A = Annual; P = Perennial; E = Erect; ET = Erect and Tall; SP = Spreading; QG = Quick growing; SG = Slow growing.

Resistance - R = Resistant; RR = Highly resistant; S = Susceptible; SS = Highly susceptible.

Sources - Agarwal 1965 and Musa 1975.

A layer of Azolla covering one hectare of rice field will produce 10 t of green matter containing 30 kg N. This amount could be doubled by growing a second layer. Water should be drained after the formation of a layer of Azolla or it should be incorporated in the soil by other means. It decomposes in 8 to 10 days after incorporation. Azolla occuring naturally in stagnant water can also be used as an organic fertilizer for crop production.

Compost of Azolla can be prepared just by keeping the green matter in moist condition for a few days. Since Azolla is rich in protein and minerals, it can be used as a good substitute of forage for cattle and feed for poultry (Singh 1977).

Azolla is now used as green compost in about 80 000 ha of land in North Vietnam where it has become an important factor in agriculture (Singh 1977). Chinese agriculture also makes extensive use of Azolla for crop production (Hauck 1977). Azolla is seeded on the standing water of rice fields and after two weeks is incorporated into the soil. This practice is normally carried out three times per season, adding 50 to 60 kg N/ha. Another practice is called "Azolla fertilizer

Table 7 N FIXATION BY SELECTED GREEN MANURE CROPS

Crop	Green matter t/ha	Moisture %	N % in wet Weight	N fixed kg/ha
Sunhemp	19.5	75.0	0.43	83.9
Dhaincha	18.4	78.2	0.43	79.1
Black-gram	11.0	83.0	0.41	45.3
Green-gram	7.4	75.0	0.53	38.8
Cluster-bean	18.4	75.0	0.34	62.6
Cowpea	13.8	86.4	0.49	67.6
Horse-gram	9.2	71.5	0.33	30.4
Indigo	8.2	44.7	0.78	71.8

Source: Singh, A. and Lal, B. In Soil Fertility - Theory and Practice. Ed. 1976 J.S. Kanwar. Indian Council of Agric. Res., New Delhi, p. 145.

factory", whereby the plant is grown intensively in breeding fields of 20 x 50 m, and 10 crops are incorporated into the silt which has been brought to the fields. At the end of the procedure the material has a high N content and is transferred to other fields for fertilization.

5.4 Algae

Free-living N-fixing blue-green algae play an important role in maintaining the N fertility of rice fields in Asia. They fix substantial amounts of atmospheric N if the level of available soil N is not high enough to inhibit enzyme activity. Fixation takes place during the early stages of plant growth, i.e. up to a month after planting, and the amount fixed varies from 2.3 to 33.3 kg N/ha (Yoshida 1975).

The work done in India on algal N fixation has been summarized by Venkataraman (1973). According to him, algal inculation has a positive influence on the growth and yield of high-yielding dwarf rice cultivars even in the presence of high levels of applied fertilizer N. The production of oxygen, growth substances and vitamins by algae seems to be responsible in part for the higher crop yield. Thus the concept of blue-green algae as a substitute for inorganic fertilization changes into one of supplementation. The wide range of tolerance of these blue-green algae to a variety of pesticides indicates that the recommended pest control measures will not hamper the growth and biological activity of these organisms. Selection of effective strains with faster rates of growth and a competitive ability will enhance algal N fixation. At the same time, production of these algae in bulk, their preservation in a viable state and distribution to farmers for inoculation are also very important. The "open air soil culture" technique developed by the above author has the advantage of being run continuously in the tropics and of being adopted by the farmers in the form of algal nursery beds. Standardization is needed with regard to an optimum quantity of inoculum, and frequency and time of application.

Apart from rice, upland crops (particularly vegetables) have also been shown to respond to algal inoculation. The minimum moisture level that can support algal growth and activity needs critical examination, and will be particularly relevant under dry land conditions without an assured water supply.

Venkataraman (1973) also cautions that algal establishment can fail due to:

i. contact with acid soils and fertilizers;
ii. lack of competitive ability because of poor growth of inoculant(s);
iii. restricted tolerance spectrum to pesticides;
iv. presence of algophages (as in sewage) and/or predators;
v. insufficient moisture level; or
vi. nutrient deficiencies.

In China, like the rest of Asia, the use of blue-green algae as an inoculum in the rice fields is still at the research stage (Hauck 1977).

Introduction of algae either as inoculum or through Azolla will substantially reduce the costly fertilizer N input for rice cultivation in Asia.

5.5 Bacteria

Selection and inoculation of high N-fixing rhizosphere bacteria and the effect of environmental factors on free N fixation are under intensive study at the International Rice Research Institute, Manila, Phillipines.

Another promising field is the fixation of N by Spirilium bacteria in the roots of tropical grasses and cereals (Dobereiner and Day 1973). If the bacterial N fixation in cereal roots becomes successful for practical use, it will greatly aid in the N nutrition of major food crops of the world.

6. NIGHT-SOIL

The use of night-soil (faeces and urine of human beings) as manure was very common in pre-war Japan, but now this practice is greatly reduced due to sanitation considerations (Egawa 1975). In India, there is very little use made of night-soil in urban areas and practically none in villages (Garg et al 1971). Night-soil fertilization of crops has long been common and popular in China (Duncan 1975).

In rural and urban settlements lacking sewers, night-soil is often disposed off by trenching which is unhygienic, requires a considerable amount of land and often leads to pollution of underground waters (Da Silva et al 1976).

Night-soil is rich in nutrients (Table 2)and the value of plant food contained in human wastes produced in India is estimated to be US $ 700 million which is equivalent to the foreign exchange cost to India of importing fertilizers. The extent to which this potential is used will be influenced by the farmers' costs, by health risks and by culturally determined attitudes (Duncan 1975).

Raw night-soil contains disease producing bacteria, protozoa, viruses and helminthic parasites. Anaerobic digestion of night-soil in biogas plants not only reduces the counts of pathogenic organisms but also yields valuable gas (65% methane, 34% CO_2 and 1% other vapours) for cooking, and nutrient-rich sludge for utilization as manure. Digested night-soil can be dried on simple sand beds much more easily than raw night-soil.

It is estimated that a family of four can produce 70-90 kg of dried sludge (rich in N and P) per year. The supernatant can be treated in small oxidation ponds, used on land after dilution, or disposed off in soak pits. The digestion of a mixture of cowdung and night-soil was found to give a better gas yield than either of the materials alone (Singh 1975).

Where there are no village latrines, a programme should be instigated to extend the habit of depositing the excreta in a small hole and covering it with soil.

This practice prevents bad smells, fly-breeding and volatilization of NH_3, and elimination of the two former will improve village sanitation.

Another safe and hygienic method of handling night-soil is by composting it with vegetable wastes under aerobic conditions. This has proved successful in safeguarding public health and in preserving fertilizer values. The internal temperature of a properly made compost heap rises rapidly and remains high for a period long enough to destroy Ascaris eggs and to give partial control of fly breeding (FAO 1962).

More intensive research work must be done in the immediate future, not only on sanitary methods of applying night-soil to the land, but also on the whole important question of its further utilization for effective recycling of nutrients and energy contained in the night-soil.

7. URBAN AND INDUSTRIAL WASTES

Urban and industrial wastes are grouped into three major classes: solid waste, waste water and sewage sludge.

Solid wastes include garbage, refuse, and other discarded solid materials of community, industrial, agricultural and commercial origin (Tietjen 1975). In municipal wastes the proportion of industrial and agricultural materials is small, while that of domestic and commercial wastes is large. Solid wastes are used for the production of urban composts or are disposed off by tipping, land fill, incineration etc. Waste water includes municipal waste water, sanitary and industrial waters, urban runoff from streets and sometimes agricultural waste waters. Sludge is the solid waste obtained from sewage treatment plants after the liquid effluent is separated from the sewage. While treated effluent is discharged into watercourses or used for irrigation, sludge is dried and used as manure. Sludge is quite difficult to handle and more expensive to dispose off than effluents. A brief discussion of how urban wastes are managed is given in the following sections.

7.1 Urban Compost

Municipal and industrial solid wastes are utilized to prepare urban compost.

In big cities, conventional methods of composting are difficult to practice because of (a) the high cost, (b) lack of labour to handle obnoxious waste materials, (c) expensive haulage of materials to distant compost grounds and (d) problems of marketing processed composts. Mechanized composting, if adopted, can solve most of the above problems and it facilitates continuous processing both in wet and dry seasons, produces good quality compost in a short time, achieves sanitary control with odour proof devices, effectively handles sludge materials for composting thereby eliminating the need for large sludge drying beds, and reduces the hauling charges and land requirement (FAO 1975).

Compost making by manual and mechanical means does not require the spending of much foreign exchange as in fertilizer manufacture; this is especially true in non-oil producing developing countries. Economics worked out for the production of composts at compost plants in India shows that it is cheaper to manfacture compost mechanically than to produce chemical fertilizers on an equal plant nutrient (NPK) basis (Anon 1975). In addition, compost supplies humus, lime and trace elements.

Mechanical composting is practised in a number of Asian countries, (e.g. India, Philippines, Thailand and Japan) and Israel. The compost plant in Israel is said to be the largest in the world with a processing capacity of 500 tonnes in one shift of eight hours, while the second largest plant is in Bangkok. In India it is planned to set up 45 compost plants in cities with a population of over 300 000 with an estimated annual production of 1.5 million t (Anon 1975). In addition, about 2 500 small urban settlements produce 0.7 million t of compost per annum (Cheema 1968). Present production of compost from all sources is only 4.8 million t as against the estimated potential of 10.8 million t. It is planned to increase this figure to 7.5 million t during the Fifth Five Year Plan (FAO 1975).

Compost is mainly used for horticultural crops in Israel, for rice in Thailand and other South East Asian countries, and for vegetables and short season crops in India. In Shanghai, garbage is transported,mainly by boat, from collecting points in the city to the communes outside the city where it is processed with night-soil. Simple storage and processing installations for garbage, without costly mechanism, can be seen in various places (Hauck 1977).

7.2 Sewage/Sullage

Sewage contains human, household and industrial wastes and sometimes urban runoff from streets flows into sewage systems. These waste waters are collected and transported through underground or open sewerage systems to points of treatment and/or disposal. In India, 100 cities and towns have complete or partial sewerage systems while 700 other towns use open drains for sewage collection (FAO 1975).

Sewage contains constituents (heavy metals and pathogenic organisms) which are toxic to plants or pose health hazards to human beings and animals. Pathogenic organisms can be excluded from sewage by proper pretreatment in oxidation ponds.

Falling levels of conventional water supplies, a growing awareness of the health hazards implicit in the rising levels of air and water pollution, especially in urban centres, and the economic benefits of cheap reclaimed water, have all prompted the treatment and purification of waste waters for reuse (Da Silva et al 1976). These authors indicate that reclaimed waters, after chlorination, can be used for recreational (water sports), municipal (street washing and upkeep of parks and gardens), agricultural (irrigation and fish culture) and industrial (cooling system) purposes. Although reclaimed waste water can be used for domestic purposes in emergency situations (as in Kansas, USA, during the 1957 drought), there are major objections to the use of purified waste water for drinking purposes. These objections stem from social constraints and fear of the possible transmission of infection due to the absence of purity standards for potable water.

Da Silva et al (1976) have also pointed out that algae can be cultivated during treatment of waste water in photosynthetic oxidation ponds. Algal oxidation ponds are in operation in Israel, Japan, Thailand, USSR, Germany and Czechoslovakia. The economic feasibility of waste water treatment in algal oxidation ponds should be worked out and, if found attractive, this system should be popularized in other developing countries.

Sewage water, treated or raw is rich in humus and nutrients (Table 8). The estimated 800 million gallons of sewage and sullage produced in India will provide 91 t of N, 18.2 t of P_2O_5, 54.6 t of K_2O and 1 456 t of organic matter everyday; it is estimated that 0.6 million t/year of extra grain could be produced by these sewage nutrients (FAO 1975). Presently about 24 000 ha of land are under sewage irrigation in about 220 urban settlements in India and these lands use 200 million gallons (25% of the total produced) of sewage every day. Details of sewage irrigation and sewage farm management are given in (FAO 1975). Properly managed sewage farms have been operating successfully in India without reported adverse effects on farm workers or neighbouring residents. Crops to be eaten raw should never be grown on a sewage farm. Crops most suited for sewage irrigation are fodder crops, grains and industrial crops such as sugarcane, cotton, jute, etc. Excellent crops can be grown with waste water irrigation, with a minimal effect on groundwater quality. However, constant monitoring of water quality in nearby wells is necessary to prevent contamination, if any, from land treatment of sewage.

Table 8

COMPOSITION OF SEWAGE AND SLUDGE
(taken from Tietjen)

Constituent	Raw Sewage ppm	Treated Sewage ppm	Sludge kg/100m^3
Total Solids	700	760 - 1 200	4 100
BOD 1/	200	10 - 42	-
COD 2/	500	30 - 80	-
Ignition Loss	-	-	2 100
N	40	10 - 60	210
P	10	10 - 25	60
K	10	10 - 40	13
Na	-	190 - 250	11
Ca	-	20 - 120	200
Mg	-	10 - 50	15
Fe	-	-	120
Cu	-	-	1.4
Pb	-	-	0.1
Ni	-	-	0.6
Zn	-	-	5.1
B	-	0 - 0.1	-

1/ BOD = Biological Oxygen Demand
2/ COD = Chemical Oxygen Demand

Factory effluents contain acids, alkali, tarry material and other obnoxious toxic compounds which, when mixed with domestic sewage, make it unsuitable for irrigation. These effluents should be treated separately to destroy these toxic substances before being mixed with municipal waste waters.

7.3 Sewage Sludge

After treatment, sewage and industrial waste waters are transformed into effluent and sludge. The former is disposed off by discharge into watercourses or to the land with a minimum disruption to nature.

Unlike in manure, the nutrient contents and their ratio in sludge are variable and highly unbalanced (Table 8). There is usually a deficiency of K and a greater portion of the total N is at once available. Fortification of sludge with K fertilizers increases the utilization of sludge-applied nutrients in soils.

Sludge also contains toxic or noxious compounds (Table 8) derived from industrial wastes and waste water. If possible, it is better to exclude industrial wastes from the public collection and from being mixed with the harmless municipal wastes. Otherwise, sludge analysis for toxic elements should determine the application rate of sludge so as not to exceed the tolerable levels of toxic elements in arable soils as given in Table 9 (Tietjen 1975).

Table 9

PROPOSED TOLERABLE LEVELS FOR NON-NUTRIENT ELEMENTS IN SOILS
(Tietjen 1975)

Element	Level ppm	Element	Level ppm
Be 1/	10	Zn	300
B	100	As	50
F	500	Se	10
Cr	100	Mo	10
Ni	100	Cd 1/	5
Co	50	Hg 1/	5
Cu	100	Pb	100

1/ Special reservation

8. BIOGAS PRODUCTION FROM WASTES

8.1 Background Information

It has been known for a long time that combustible marsh gas can be produced from decaying organic wastes and that a major constituent of this gas is methane (ICAR 1976).

At the beginning of this century, the method of anaerobic fermentation or "digestion" was successfully applied to the treatment of sewage sludge and a by-product of this process was a large amount of methane gas. However, the application of this method to other material did not receive much attention until recently.

The principle of cow-dung ("Gobar") gas plants was first evolved in India (Desai and Biswas 1945) for production of fuel as well as manure from cattle dung. More details of design, construction, maintenance and cost-benefit analysis of biogas plants can be found in ICAR (1976), the report of a committee set up for the "Assessment of the Cost Benefit Effects of Cow-dung Gas Plants" in India. Another source of information is the book by Sathianathan (1975).

8.2 Design

Basically, the cow-dung gas plant is a brick lined fermentation well, known as a digester, which is completely filled with dung made into a liquid slurry by mixing it with an equal amount of water (Fig 5). This well is covered at the top with an iron drum or gas holder introduced upside down into the well, which serves to cut off air and provides the necessary anaerobic conditions for fermentation. The gas produces bubbles into the inverted drum which then.begins to float and rise. Through an opening on the top of the drum, the gas can be led to the kitchen or other points of use by means of pipes. Maintenance of gas production is achieved by feeding daily required amounts of dung slurry through a funnel pipe which carries the fresh slurry to the bottom of the well. The digested or spent slurry overflows from the top of the well through an outlet pipe and collects in a pit for periodic removal.

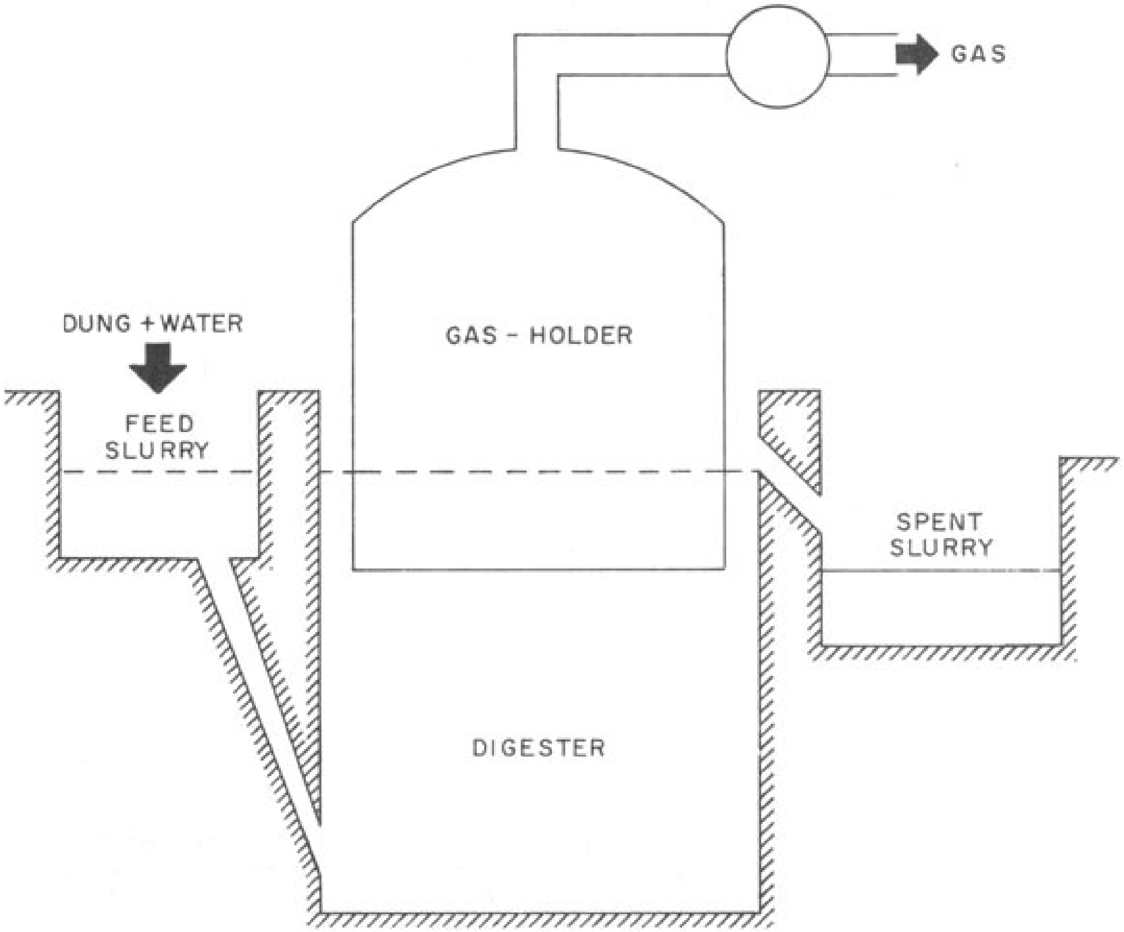

Fig. 5 BASIC DESIGN OF A BIOGAS PLANT

(after Prasad et al 1974)

8.3 Biogas Characteristics

The approximate compostion of the gas evolved from a cow-dung gas plant is as follows:

	%
Methane	50 - 60
Carbon dioxide	30 - 40
Hydrogen	5 - 10
Nitrogen	4 - 6
Hydrogen sulphide	Traces

The gas burns with a non-luminous blue flame and has a calorific value of 4 713 kcal/m^3. The characteristics of biogas are compared with those of other fuels in Table 10 (KVIC 1975). When burnt in suitable burners, the heat utilization efficiency of cow-dung gas is nearly 60% as compared with 50% for kerosene, 17% for fire-wood and 11% for cow-dung cakes. It is also clear from Table 10 that one cubic metre of biogas is equivalent to 0.62 l of kerosene, 3.47 kg of fire-wood, 12.30 kg of dried dung-cakes, and 4.70 kWh of electricity. The only hitch is that the biogas cannot be compressed into liquid form like natural gas for storage and distribution purposes.

Table 10 COMPARISON OF COW-DUNG GAS WITH VARIOUS FUELS (KVIC 1975)

Name of Fuel	Calorific value kcal	Thermal efficiency %	Effective heat kcal	Replacement value for biogas
Cow-dung gas (m^3)	4 713	60	2 828	1.00
Kerosene (litre)	9 122	50	4 561	0.62
Fire-wood (kg)	4 708	17	814	3.47
Cow-dung cakes (kg)	2 092	11	230	12.30
Charcoal (kg)	6 930	28	1 940	1.46
Soft Coke (kg)	6 292	28	1 762	1.61
Natural gas (kg)	10 882	60	6 529	0.43
Furnace oil (litre)	9 041	75	6 781	0.42
Coal gas (m^3)	4 004	60	2 402	1.18
Electricity (kWh)	860	70	602	4.70

8.4 Characteristics of Spent Slurry

Anaerobic digestion has been found to be more efficient in respect of N conservation than aerobic methods. The spent slurry obtained from the gas plant is richer both in quality and quantity than ordinary compost or the original dung. Data in Table 11 give the amounts of manure obtained when one tonne of fresh dung is processed by the traditional Indian method and through a biogas plant. Loss of organic matter is very low and that of N is almost nil in the fermentation process as compared to the traditional open air decomposition of dung (Garg et al 1971). The range of N, P and K contents of cow-dung slurry is as follows:

	%
N	1.4 - 1.8
P_2O_5	1.1 - 2.0
K_2O	0.8 - 1.2

Table 11 MANURE OBTAINED FROM ONE TONNE OF FRESH DUNG (0.25% N) PROCESSED BY THE TRADITIONAL INDIAN METHOD AND THROUGH A GAS PLANT (Garg et al 1971)

Characteristics	Traditional method	Through gas plant
Organic matter loss by decomposition	500 kg	270 kg
N loss by decomposition	1.25 kg	Nil
Final manure quantity	500 kg	730 kg
Manure Quality - N % on dry basis	1.0	1.3
Additional advantage	None	57 m^3 of gas for cooking

The wet slurry can be applied directly to the fields with the irrigation water or can be dried in a series of beds for making manure. It is superior even to farmyard manure in its effect on crop growth and also in its power to improve soil physical properties (Achorya 1957).

8.5 Factors Affecting Gas Production

i. Temperature

The optimum temperature for methane bacteria is 30-35°C. The rate of gas production per kg of fresh dung added daily varies from 0.09 m^3 in the summer months to about 0.04 m^3 in the winter months. The addition of cattle urine, dried powdered leaves or straw stimulates gas production in winter (Chawla 1973).

ii. pH

A neutral to slightly alkaline reaction is the best and organisms become inactive below pH 6.0.

iii. Dilution

A level of 7-9% total solids in the slurry is optimum and this can be achieved by mixing together equal amounts of water and dung.

iv. Reaction time

About 90% of the total gas production is obtained within a period four weeks at the optimum temperature.

v. Nature of organic materials

Gas production is high in the case of materials that are rich in celluloses or hemicelluloses and that also contain sufficient proteinaceous substances, e.g. sunhemp, dhaincha, groundnut shell and sugarcane bagasse.

vi. Night-soil and cow-dung mixture

Night-soil alone produces four times as much gas as cow-dung alone on the basis of equal weight of volatile solids added per day. Even a 25:75 mixture of night-soil and cow-dung increased the volume of gas produced by nearly 60% (Mohan Rao 1974).

vii. Stirring

Occasional stirring of the slurry during digestion breaks the scum formed on the surface and increases decomposition and gas production.

8.6 Pattern of Rural Energy Consumption and Biogas Potential

The pattern of fuel consumption in rural India is depicted in Table 12 (NCEAR 1965). Fire-wood is the largest single source of heat in the rural sector followed by dung cake and vegetatable wastes. The commercial fuels, common in urban areas, account for a mere 5.4% of the total energy needs of a village population. It is also important to note that about 77% of the fire-wood, 98% of the dung cake and all the vegetable wastes are obtained free of cost in rural areas. In fact a rural population buys only 20% of its entire energy requirement. This pattern is pretty much the same in other developing countries of Asia and Africa. The real energy crisis is shortage of fire-wood (Garg and Thanvi 1977). Thus the development of biogas and other alternative energy sources in rural areas must be given top priority in order to stop indiscriminate cutting of forest trees and wasteful use of cow-dung and crop residues.

It is estimated that a potential biogas energy output of a village of 250 inhabitants living in 100 dwellings and possessing 250 head of cattle is about 667.5 kWh per day which exceeds the present energy consumption of 500 kWh per day in a village of this size in India. The biogas energy output of such a community is sufficient for 10 pumpsets (200 kWh), five manufactories (50 kWh), one light in every house (67.5 kWh), energy for cooking in each dwelling (200 kWh) and 150 kWh for various other purposes (Prasad et al 1974). This potential must be realized in order to reduce the energy shortage in rural areas.

Table 12

PATTERN OF FUEL CONSUMPTION IN RURAL INDIA
(NCEAR 1965)

Fuel	Percentage Share	Fuel	Percentage Share
A. Commercial		B. Non-commercial	
Soft coke	1.6	Fire-wood	58.6
Kerosene	3.8	Dung cake	21.0
Electricity, gas, etc.	Negligible	Vegetable wastes	15.0
		Charcoal, oil, etc.	Negligible

8.7 Benefits of Cow-dung Gas Plants

The benefits derived from cow-dung gas plants may be classified as tangible or intangible, also as social or individual. The tangible benefits are:

> rich weed-free manure; economic and efficient source of fuel; 25-50% saving in cooking time, and saving in fuel expenses.

The intangible benefits include comfort or convenience and also a gain in prestige. The social benefits are:

> saving in foreign exchange for fertilizer; saving of forest land (0.12 ha of forest land per annum is saved by a gas plant of 3 m^3/day size), and better sanitation in the villages. The individual benefits include a cleaner and more economical cooking fuel and also a rise in the standard of living.

8.8 Cost Benefit Analysis of Biogas Plants

The installation costs of cow-dung gas plants depend upon a number of factors such as the plant design, plant size and the local cost of material, labour, etc. Indian designs based on a concrete digestion-well and steel gas holder are quite expensive as shown in Table 13. The Chinese make the cheapest biogas plants (about US $25 each for household size plants) as reported by Hauck et al (1977). It is understood that the Republic of Korea has a collapsible biogas plant made of plastic; its cost is not known at present. The only way to popularize biogas plants in rural Asia is to make the installation and maintenance cost very cheap. There is also a genuine need for a suitable extension agency to educate the people in the installation and proper maintenance of biogas units.

Maintenance costs are mostly related to the repair of well walls, change of side sheets and repairs (mainly painting) or replacement of the gas holder.

Selected economic data on cow-dung gas plants of various sizes are given in Table 13. Savings in fuel costs due to the use of biogas plants range from about Rs 500 to Rs 700 per year for different plant sizes. The benefit-cost ratios show a high rate of return on investment in biogas plants and they increase with the plant size. The capital investment can be recovered in 4 to 6 years. The pay-back period becomes smaller for larger gas plants. The financial viability of the investment in cow-dung gas plants is thus established beyond doubt.

Table 13

ECONOMIC DATA ON COW-DUNG GAS PLANTS
(ICAR 1976)

Items	Plant size, m^3/day			
	3.0	4.5	6.0	7.5
Installation cost (Rs) 1/	1 900	2 190	2 740	3 110
Dung input, kg/day	46	54	84	99
Operating time, min/day	36	51	49	-
Annual saving on fuel cost (Rs) 1/	520	510	640	680
Benefit/cost ratio	2.07	-	2.96	-
Internal rate of return on capital, %	24.0	-	34.7	-
Pay-back period, years	6.0	-	4.0	-

1/ Rs 1.00 = US $0.12

8.9 Problems against Wide Use of Biogas

There are some major problems militating against a more widespread adoption of cow-dung gas plants; they are:

i. high installation costs;

ii. marked fall in gas supply during winter;

iii. heavy corrosion of gas holders;

iv. necessity to own or have access to a large number of cattle;

v. lack of suitable extension, maintenance/servicing facilities;

vi. problems connected with slurry disposal due to clustered nature of village houses in certain areas;

vii. social prejudice against acceptance of dung-cum-night-soil gas plants;

viii. lack of alternative sources of fuel for villagers who do not own any cattle.

A consequence is that the cow-dung gas plant is beyond the reach of all but the cattle-owning rural rich. It does not as yet provide a solution to the "whole-village" energy problem in India.

8.10 Research and Development Need

There is an urgent need for a coordinated research and development effort in the fields of chemical engineering and fermentation technology for the solution of some of the above problems. The socio and techno-economic aspects of the situation also cannot be ignored. Plant costs should be reduced by evolving new designs that are efficient in fermentation, cheap and easy to operate and can be moved from one place to another when necessary. The reasons for the low cost of biogas plants in China, as reported by Hauck et al (1977), should be thoroughly examined and feasible lines of approach adopted in other countries. The newly designed collapsible plastic biogas plants developed in the Republic of Korea should be examined for cost and efficiency.

8.11 Actual Performance in Asia

More than 16 000 cow-dung gas plants have been installed in India over a span of nearly 25 years. It is planned to have a total of 100 000 plants in the country by the end of Fifth Five Year Plan period. Biogas plants based on night-soil are few in India, but abundant in China. The use of biogas has become popular in various parts of China and is still expanding rapidly. Reports (Anon 1976) indicate that about 300 000 gas units have been installed in China during a short period of campaign in 1976. Chinese feed the methane gas plants twice weekly with a combination of 10% night-soil, 40% animal manure and 50% vegetable wastes. The mixture should maintain a pH of 7.5; the flame should be blue; and if it showed red, this meant that more material must be added. The same report observes that there was no obnoxious smell from the biogas plants which are just outside the kitchen wall. In certain countries, more than 70% of the households have biogas plants. One of the important factors for the popular and wide-spread use of biogas in China is the unbelievably low installation and maintenance cost of gas plants; a household size plant costs only US $25 (Hauck 1977): There is a methane service unit in each county for efficient maintenance of the installed units. Biogas is also becoming popular in the Republic of Korea where there are 29 000 plants at present (Da Silva et al 1976).

9. ORGANIC RECYCLING AND SOIL FERTILITY

Use of organic materials to build up soil fertility is an age-old practice in Asia. The continuous addition of organic materials with or without mineral fertilizers will help to maintain the soil organic matter at a reasonable level. The only exception is green manuring where the added immature tissues of green plants decompose (Nye and Greenland 1960; Agarwal 1965; Singh 1975). Singh (1967) has shown, on the basis of data from the Pusa Permanent Manurial Trial started in 1908, that green manuring has not resulted in any great change in the organic matter content of the Pusa soil; similarly there is no change in soil bulk density and moisture characteristics due to long-term green manuring (Biswas et al 1964). Data from other tropical countries reviewed by Joffe (1955) and the long-term experiments in India show conclusively that green manuring is incapable of appreciably increasing the organic matter content in soils. Most of its beneficial effects are explainable in terms of the nutrient contents.

On the contrary, the addition of carbonaceous materials for in situ decomposition in soils slightly increases their humus content, improves soil aggregation, structure and porosity (aeration), promotes water percolation, water retention and root proliferation, and reduces runoff and soil erosion (Joffe 1955; Charreau 1974; Egawa 1975; Stickelberger 1975; Tietjen 1975; Epstein et al 1976). It is also shown that the application of pre-rotted organic wastes, such as farmyard manure or compost, may bring about a less significant improvement of soil structure (Krishnamurthy and Venkateswarlu 1976). The most effective C/N ratio of organic wastes, that are good for direct incorporation to improve soil physical properties, is between 75 and 150; to this class belong the straws, groundnut shells, rice-husks and other plant residues. The mean weight diameter (MWD) of soil aggregates obtained under different treatments of laboratory incubation study (Krishnamurthy and Venkateswarlu 1976) is as follows:

	Treatment	MWD (Microns)
1.	Control	339
2.	Compost	347
3.	Jowar Straw	449
4.	Cassia leaves	1185
5.	Glucose + Am. Sulphate	1365

Thus in situ decomposition is necessary for promoting soil aggregation.

Increased humus content is also believed to decrease soil compaction during dry seasons due to the inactivation of iron hydroxides which otherwise will crystallize and harden ferruginous soils (Greenland 1972). This point needs further confirmation by research data from other tropical countries.

The most important chemical effect on soils is the addition of nutrients. Humus can be considered to be a storehouse of various nutrients essential to plant growth.. On an average, soil organic matter contains 0.05% each of P and S in addition to cations and trace elements. A 15 cm layer of soil with 0.5% organic matter, therefore, contains nearly 500 kg N and 100 kg each of P and S per hectare. The N content of soil organic matter may reach 6 000 kg/ha (Yoshida 1975) depending upon climate and soil factors as well as cultivation practices. The nutrient content of various organic materials is furnished in Tables 2 and 4. Most of the wastes are low in P while sludges are deficient in K. Fortification of manures with missing elements greatly increases their nutrient supplying capacity when applied to soils.

The addition of organic matter to flooded soils stimulates: a) nutrient supply, b) bacterial N fixation in the surface soil, c) release of certain organic compounds which promote rice growth, d) CO_2 production in the ground surface which enhances rice photosynthetic acitivity, and e) the production of ethylene gas which favours the control of soil pathogens (Yoshida 1975). Algal inoculation reduces the contents of oxidizable matter, total sulphides and ferrous irons in soils where iron and sulphide toxicity is a common phenomenon (Venkataraman 1973).

Legumes are a great source for augmenting the N reserves in soil and have a place in any programme for building up soil fertility (Kanwar 1976) because they have a favourable residual effect on soil fertility through roots and fallen leaves (Singh 1975). Techniques of N fixation through bacterial fertilizers are also important in future fertility programmes.

Organic wastes alone can hardly be depended upon as the sole source of nutrients for crops. The most satisfactory method of improving soil fertility is to use a judicious combination of organic wastes and inorganic fertilizers. The optimal ratio for the supply of nutrients through organic and inorganic sources is between 3:7 and 7:3 depending upon the availability and cost of manures and fertilizers. In China, this ratio remains at 7:3 (Hauck 1977).

Organic wastes, fresh or decomposed, have an high indigenous microbial population, the exact role of which in decomposition and soil fertility is not known and must be examined in future research (Parr 1975). Since organic matter supplies energy and nutrients to soil organisms, soils rich in humus always carry a large and active microbial population. This might be the reason for the stimulation of non-symbiotic N fixation in soils treated with straw and P fertilizers (Deavin 1974; MacRae and Castro 1967; Primavesi and Primavesi 1974). Organic amendments always stimulate the growth of several organisms rather than stimulating the proliferation of a particular species; the resultant organism diversity ensures a healthy biotop characterized by a large number of species and a low individual count (Stickelberger 1975). The same author points out that, in nature itself, the one-sided use of fertilizers causes a proliferation of a particular species which soon develop into a pest that cannot be held in check by other organisms. The intensive use of pesticides then disrupts the ecological balance. Contrary to this ecologist's view, other reports indicate that pathogenic organisms are also stimulated along with other organisms by organic amendments (Ayanaba and Okigbo 1975. Whether a diseased condition is initiated, increased or decreased, then depends on the presence of a suitable host at the time, the status of antagonists and the prevalent environmental conditions.

10. ORGANIC RECYCLING AND CROP YIELD

In general, the favourable changes produced in soil properties by the addition of organic materials improve soil fertility and increase crop yields. However, the exact nature of crop response to manures depends on the degree of decomposition of materials, C:N ratio, content and balance of nutrients, time and rate of application and the type of crops and soils. Fresh wastes are always low in available plant nutrients and high in growth inhibitory substances and therefore some kind of decomposition, either in situ on the field or away from the field, is necessary prior to planting of crops. The growth inhibitory action of fresh wastes may be due to N immobilization (Charreau 1974; Yoshida 1975), toxic substances or intermediate decomposition products (Schuman 1975; Sidorenko 1977; Langdale 1970; Linderman 1970; Yoshida 1975; Tietjen 1975). Fresh compost can be used for mulching, waste land reclamation and reforestation, while well rotted compost or manure is needed for agricultural and horticultural uses (Tietjen 1975).

The N immobilization effect of carbonaceous wastes with a wide C:N ratio can be corrected by the simultaneous application of N fertilizers along with residues or by incorporating organic materials well before planting a crop. Most organic wastes except sludge are low in P while the latter is deficient in K. Fortification and balancing of deficient elements in wastes increases crop yields and ensures complete uptake and better utilization of applied nutrients. Waste application in amounts greater than crop N requirement results in lodging, late maturity, reduced yield, unbalanced nutrition and undesirable plant composition (Lahann 1976 and McCalla 1975). A thumb rule to calculate the N release from manure is that about 50% of the N in wastes will be mineralized in the first year, 25% the second year, 12% the third year and so on. Crops also differ in the extent to which they respond to dressings of organic manures. As shown in Table 14, rainy season crops, like paddy, maize, sorghum, have been found to be more responsive to manures than winter season crops like wheat, barley or oil seeds (Agarwal 1965). The response ratio of wheat to N application through organic manures varies from 1.2 to 6.2 depending on the type of materials and soils (Table 15).

Table 14 AVERAGE RESPONSE OF RAINY AND WINTER SEASON CROPS TO MANURES IN INDIA (Agarwal 1965)

Crop	Manure	N-dose kg/ha	kg grain/ kg N
Rainy Season Crops			
Sorghum	Farm manure	11 - 33	4.3 - 9.0
Millet	Compost	56	3.6
Ragi	Farm manure	56 - 90	4.2 - 5.8
Maize	Farm manure	56 - 112	8.0 - 12.0
Groundnut	Farm manure	22 - 33	3.0
Winter Season Crops			
Wheat	Farm manure	11 - 129	2.3 - 4.4
Wheat	Compost	56 - 90	1.2 - 2.7

Data in Table 16 taken from Agarwal (1965) illustrate that, except for arhar, only slightly lower yields have been obtained for maize and oats with farmyard manure than with a complete mineral mixture in a long-term experiment at Pusa, India. In another long-term trial conducted at Pusa with a rotation of maize, oat, pea, wheat and gram, manure plots out-yielded the fertilizer plots on an equal nutrient basis

Table 15 AVERAGE RESPONSE OF WHEAT TO MANURES IN INDIA
(Agarwal 1965)

Soil group	Type of manure	Added N kg/ha	kg grain/ kg N
Black Soil	Cattle dung	-	6.2
(Vertisol)	Farmyard manure	11 - 56	4.4
	Farm compost	-	1.7
Gangetic alluvium	Cattle dung	72	1.6
(Inceptisol)	Farmyard manure	129	3.6
	Compost	90	2.7
Indus alluvium	Farmyard manure	-	2.3
(Inceptisol)	Compost	-	2.4
Kanpur soils	Compost	56	1.2
	Am. Sulphate	56	8.6
	Compost + Am. Sulphate	56	6.9

(Agarwal 1965). Use of organic manures as basal dressings along with fertilizers enhances the effects of the latter and nullifies the harmful effects, if any, of long-term fertilizer use (Agarwal 1965; Bache and Heathcote 1969). A combination of organic manures and mineral fertilizers produces better yields than those obtained by exclusive use of the latter (Egawa 1975). This author also reports that leading Japanese farmers who were awarded prizes in rice yield contests invariably applied large amounts of composts on their fields.

Benefits from legumes and green manures last only for the following crop in tropical climates, because the effects are primarily due to mobilization of nutrients and not to improvements in the N and organic matter contents of soils (Scherbatoff 1940; Joffe 1955). Data in Table 17 (Singh 1975) indicate that the "legume effect" (tops removed and only roots ploughed in) and "green matter effect" (only the tops or shoots transported from other fields and ploughed in) are each responsible for 50% of the effect of green manuring (Singh 1963 and 1965a). Experiments designed to measure the increase in the yield of sugarcane treated a) after the whole sunhemp crop was ploughed in and b) burnt in situ, also confirmed this surmise (Singh 1965b). Since the "legume effect" appears to be more important than the "green matter effect", it is possible to substitute green manures with fodder or grain legumes which contribute to other crops the fixed N contained in their roots and nodules. The increase produced in yields of maize grain over fallow plots by different legumes range from 590 to 2 200 kg/ha (Table 18 taken from Singh 1975). Similar effects have been observed in tropical Africa (IAR 1977; Jones 1974) where it was shown that growing legumes in rotation with cereals always increases the yield of the latter. Thus the legumes can be planted in sequential and intercropping systems, in growing and established orchards and with plantation crops in multilayer cropping for increased total yield (Singh 1975).

Sewage irrigation supplies both water and nutrients to soils and produces excellent crops (FAO 1975; Duncan 1975).

Table 16

MEAN CROP YIELDS (kg/ha) IN PERMANENT MANURIAL PLOTS, PUSA, INDIA

(Agarwal 1965)

Experiments	Treatment		
	Control	Farmyard manures	Fertilizers
Old Series: 1908–1930	(Average of 22 years)		
Maize	736	963	1 094
Arhar	1 074	1 152	829
Oats	727	988	1 062
Revised old Series: 1930–1946	(Average of 17 years)		
Maize	459	1 230	861
New Series: 1932–1946	(Average of 15 years)		
Maize	232	471	443

Table 17

YIELD OF SUGARCANE FOLLOWING INCORPORATION OF DIFFERENT PARTS OF THE SUNHEMP (CROTALARIA JUNCEA)

(Singh 1975)

Treatment	Cane Yield, Q/ha					
	1953–54	1954–55	1955–56	1956–57	Mean	Mean as % of control
Control	634	529	247	353	441	100
Tops only (G.M. effect)	764	699	282	376	530	120
Roots only (Legume effect)	698	703	306	427	534	121
Whole – plant (Tops + Roots)	829	765	389	482	616	140

Table 18

MAIZE YIELD INCREASE OVER FALLOW PLOTS BY DIFFERENT LEGUMES (kg/ha)

Legumes	1965	1966	Mean
Trifolium alexandrinum (Berseem)	1 710	2 220	1 965
Melilotus indica (Senji)	1 160	1 190	1 175
Pisum sativum (Pea)	590	890	740

Fertilization with Azolla increases crop yields significantly. Singh (1977) observed in pot experiments that the growth and yield of transplanted rice (IR8) were better when Azolla was incorporated than when left floating. The increase in yield was up to 300 and 100% in incorporated and unincorporated treatments respectively. The data from field experiments shown in Table 19 indicate that paddy grain yields are significantly higher in Azolla plots than in the control. Other experiments conducted to test the effect of N fertilizer and Azolla on crop yields revealed that paddy containing 30 kg N fertilizer plus one layer of Azolla and 50 kg N fertilizer plus one layer of Azolla was better than 50 kg N and 80 kg N, respectively (Singh 1977). Azolla plants also suppress the growth of angiospermic weeds in flooded rice fields.

Table 19

EFFECT OF AZOLLA INCORPORATION ON YIELD (kg/ha)
OF HIGH YIELDING RICE CULTIVARS
(Singh 1977)

Treatment	Rabi, 1976	Karif, 1976		
	IR-8	Vani	Supriya	IR-8
Control	3 844	3 340	3 445	4 237
Azolla	5 313	4 148	4 416	4 708

11. ORGANIC RECYCLING AND ENVIRONMENTAL QUALITY

Heavy industrialization and urbanization intensify environmental pollution because they generate enormous wastes. Agriculture, on the contrary, helps to dispose of organic wastes safely and at the same time, recycles the nutrients which enhance the conservation of soil fertility.

Environmental problems of excessive loading of wastes on land are: a) excess NH_4-N in the upper soil layers and NO_3-N in percolating water; b) heavy metal and salt accumulation in soils; and c) production by anaerobiosis of obnoxious, odorous (amines, mercaptans, H_2S) and phytotoxic (NH_3, H_2S, certain organic acids) compounds (Parr 1975; Egawa 1975; Schuman 1975). Thus the excess application of any waste to land eventually leads to environmental pollution. The acceptable loading rate/ha/year is 25-50 tonnes for manures (McCalla 1975) and 25-75 tonnes for compost (Parr 1975).

Raw night-soil, sewage and digested sludge contain pathogenic bacteria, protozoa, viruses and helminthic parasites. These wastes constitute potential environmental and health hazards in cities and villages. Only proper treatment of wastes can eliminate these harmful organisms from waste reclaimed products. Contamination of potable water supplies often results from the seepage of untreated wastes and water through soil or because of structural defects in waste disposal systems. Inadequate public health standards due to poor sanitation systems and lack of personal hygiene lead to the spread of many diseases in thickly populated areas. Discharge of raw or treated sewage into streams and rivers pollutes the water and renders it unsuitable for drinking, washing and bathing, for use in the food industries, and for numerous other purposes essential to the health and welfare of man. This practice also spreads human and animal water-borne diseases (Da Silva et al 1976).

Proper treatment of sewage in treatment plants and oxidation ponds yields many useful products - purified water for reuse, animal feed concentrate from algae and valuable manure (Da Silva et al 1976; Tietjen 1975). Processing of dung, night-soil, sludge and other biodegradable wastes through biogas plants not only renders them safe for manurial purposes but also yields fuel energy in the form of methane gas. Biogas treatment achieves sanitary waste disposal, improved public health, conservation of energy and other natural resources, pollution control and savings on foreign exchange needed for the importation of fertilizers.

Sludges may contain toxic or obnoxious compounds derived from industrial wastes and waste water. It is better to exclude the industrial waste from the public collection and from being mixed with the harmless municipal wastes (Tietjen 1975). Harmful wastes high in toxic elements (Table 20) require special disposal methods so as not to pollute the environment. Sludge containing large amounts of heavy metals, if applied to agricultural lands, may produce unhealthy food and fodder unsuitable for consumption (Lahann 1976). There are reports that anaerobically digested dehydrated sludge is not microbially sterile and may contain pathogenic organisms (Edmonds 1976). Dry digested sludges are safer than moist settled sludges for use as manure. Thus continuous monitoring of sewage and sludge by analysis for toxic elements and pathogens is a prerequisite to eliminate health hazards to human beings and animals. Food products obtained from sewage and sludge-treated land should be thoroughly examined for carry-over of toxic substances and pathogenic organisms.

Table 20

TRACE ELEMENT CONTENT OF SOME ORGANIC WASTES
(ppm, dry matter basis)

Waste	Fe	Mn	Zn	Cu	B	Mo	Co
Oil cakes	359	44	57	22	18	3	-
Wastes of agricultural industries	678	117	43	24	14	3	-
Fish cakes	268	-	86	11	-	2	-
Bone meal	266	-	120	6	-	1	-
Fresh manure	-	201	96	16	16	20	1

Sources: Egawa 1975; and McCalla 1975

When animal wastes are upgraded into usable feed supplements or converted into single cell proteins (SCP), good process control and proper handling of the product are needed to assure high quality products. Due to the variable sources of wastes, it is essential to determine that the raw material is free of all possible harmful substances such as drugs, pesticides, trace elements, toxins, parasites and pathogenic organisms, (Taylor et al 1974; Fontenot and Webb 1975). Salmonella found in animal excreta form the greatest health hazard in animal waste recycling. Among farm animals, salmonellosis is most prevalent in turkeys, followed by chickens, cattle and swine (Morse and Duncan 1974). Fortunately, salmonella is easily destroyed by the acidity and heat produced during the processing of wastes by microbial digestion. The ensiling process kills both salmonella and parasitic nematodes found in wastes (Ciordia and Anthony 1969).

Long-term studies are needed with specific emphasis on the possible concentration of feed additives and pathogens in the oxidation ditch liquid in order to rule out disease transmission to animals and human beings when unprocessed liquid wastes are used in oxidation ditches (Vetter 1972; Harmon et al 1972; Harmon and Day 1975). No disease problems have been reported from the inclusion of poultry wastes in practical rations for beef cattle (Drake et al 1965; El-Sabban et al 1970; Fontenot et al 1971) and sheep (Noland et al 1955). Unlike cattle, sheep are sensitive to dietary copper (Underwood 1971) and using poultry litter containing high levels of copper as feed develops copper toxicity in sheep. Thus safety and product quality standards can be met if adequate precautions are taken to exclude contamination and carry-over of pathogens and other toxic substances from certain wastes to animals and man.

12. SUMMARY AND CONCLUSIONS

Organic wastes represent a potential storehouse for an immense quantity of energy and nutrients. Whether to make full use of these wastes by properly designed waste recycling projects or to fritter away these valuable resources by indiscriminate disposal is left to our decision.

There is tremendous technical scope for the use of organic wastes as nutrient sources in agriculture and animal husbandary. But this potential is not realized in practice because of certain problems connected with organic wastes. They are:

i. scattered and bulky nature of organic wastes requiring expensive collection and transport systems;

ii. presence of local uneconomic alternative uses for wastes like crop residues, dung etc;

iii. culturally determined distaste for handling certain wastes (night-soil, sewage, etc);

iv. health hazards due to possible toxicity and transmission of disease-producing organisms through food chains;

v. lack of research and development for efficient waste management; and

vi. lack of appropriate technology and consultancy services in productive waste management.

Duncan (1975) estimates that the total amount of wastes produced in developing countries contains about 130 million tonnes of NPK nutrients which is about 8 times the amount of nutrients applied through mineral fertilizers in these countries. If the Asian countries revise their agricultural strategy to utilize organic wastes as manures on a large scale, it will help to reduce their dependence on costly imported fertilizers and save their hard earned foreign exchange. Crops respond best when manures are applied in combination with fertilizers.

In the intensive use of organic materials for crop production in China, main emphasis is placed on the use of locally available organic materials for fertilization and the use of mineral fertilizers only as a supplement. The Chinese presently supply 70% of the crop nutrient requirement through manure and only 30% from chemical fertilizers (Hauck 1977). India is also intensifying its efforts to maximize the use of organic materials as fertilizers as exemplified by the data in Table 21. There is extensive use of Azolla as a green fertilizer in North Vietnam and China.

Animal and other organic wastes could be utilized most effectively and feasibly through microbial fermentation which yields food or feed from unconventional sources independent of land use and climatic conditions (Ranjhan 1977). The processed wastes, when used as animal feed, would also spare the otherwise limited food resources (grains and vegetable protein) for human consumption.

Research on symbiotic and non-symbiotic N fixation through bacteria and algae promises a large pay off in the future because of its importance in ecology and soil resources development and its large potential for crop production (Yoshida 1975). N can be obtained almost at no cost from biological fixation. It is estimated that rhizobial N fixation on a global basis amounts to 14 million t/year as against the industrial N fixation of 30 million t/year (Nagar 1975). Practical problems such as farmers lack of knowledge in the use of rhizobia, commercialization of really bad

Table 21 TARGETS AND ACHIEVEMENTS IN ORGANIC WASTE UTILIZATION IN INDIA

Programme	Fifth Plan Target	Achievements 1974-75	1975-76	1976-77	Target 1977-78
Mechanical compost plants	35	1	10	8	11
Sewage scheme	250	59	127	18	46
Family size biogas plants	100 000	10 711	18 718	15 000	25 000
Community gas plants	25	-	-	-	25
Biogas from night-soil	-	-	-	-	20
Award of prizes for maximum organic waste use (million Rs)1/	0.339	-	0.035	0.039	0.133
Pilot projects on manual composting	15 000	-	-	7 200	7 800
Green manuring (million Rs) 1/	-	-	-	-	1.00

1/ Rs 1.00 = US $0.12

inoculants due to absence of quality control, and lack of proper support media for efficient storage of inoculants have to be solved in order to make a break through in biological N fixation in developing countries (Batthyany 1975).

Continued long-term use of organic materials improves the physical, chemical and biological properties of soils and maintains their productivity. In situ decomposition of organic materials is essential for improvement in soil aggregation and structure. Use of manures as basal dressing along with fertilizers enhances the effects of the latter and nullifies the harmful effects, if any, of long-term mineral fertilizer use. Fortification of deficient elements in wastes greatly increases their nutrient supplying capacity when applied to soils. It should be emphasized here that organic fertilization should not be confused with "organic farming" as conceived in certain developed countries. The main thrust in developing countries is to use the organic materials and mineral fertilizers in judicious combinations to achieve optimum yields and not to completely replace the fertilizers with manures.

Excessive application of wastes on land increases environmental pollution, impairs crop quality and reduces final yield. Special precautions must be taken when night-soil, sewage and sludges are to be used as manures on agricultural land. Farmyard manure and composts can be used as organic fertilizers without any reservation and fear of health hazards.

Efficient waste management ensures a clean and healthy environment. In addition, several waste reclaimed products are made available for use by animals and human beings. Wastes can be put to several uses through properly designed waste recycling systems. For instance:

i. crop residue disposal through animals yields milk, meat and work apart from manure;

ii. treatment of organic wastes through biogas plants supplies energy as well as animal feed and manure

iii. photo-synthetic oxidation of sewage, sludge and night-soil in algal ponds yields protein feed for animals, reclaimed water for re-use and oxidized sludge for use as fertilizers;

iv. microbial fermentation of wastes produces acceptable feed stuff for animals, non-conventional food sources (single cell protein) for human use as well as vitamins, hormones and manures;

v. non-degradable wastes and digested sludges can be used for road-filling and land-filling as well as the manufacture of bricks and roof slates.

A few examples of food and other products obtained as a result of microbial action on natural and industrial wastes were provided in Table 1 taken from Da Silva et al (1976).

In short, organic wastes are nothing but resources out of place. These wastes, whatever the source, need to be transformed into utilizable products. In this process, agriculture offers a safe and economic solution for waste disposal. Thus organic recycling in agriculture helps

- to build soil fertility and maximize food production,
- to minimize manufactured energy inputs,
- to eradicate potential health hazards,
- to maintain a clean and healthy environment, and
- above all, to conserve our dwindling natural resources and preserve the natural ecosystem.

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Paper 19

CHINESE EXPERIENCE WITH GREEN MANURING AND RECYCLING OF CITY GARBAGE AND ITS APPLICABILITY TO AFRICA

R. Sant'Anna [1]

1. INTRODUCTION

The Chinese economy and agricultural development have been soundly based on the maxim of self-reliance as it was declared some years ago. To support the needs for food of a population of 800 million presupposes a very intensive fertilization programme, based mainly on organic materials as the national production of chemical fertilizers is still insufficient. In this paper, only green manure and the recycling of city garbage are discussed.

2. GREEN MANURE

The crops usually used in Chinese agriculture as green manure are: Astragalus sinicus, Vicia villosa, Vicia faba, Vicia sativa, Medioago sativa, Pisum arvense, Sesbania cannabina, Melilotus officinalis, Crotalaria juncea, and Phaseolus aureus. Among them, Astragalus sinicus, Vicia sativa, Crotalaria juncea and Sesbania cannabina are the most used. The methods of green manuring are summarized as follows:

i. the green crop is sown earlier and ploughed under before cultivation of the land;

ii. the green crop is harvested and applied to other fields where it is ploughed under immediately;

iii. the harvested green crop is used for feeding pigs and the pig manure and weeds are brought to the field;

iv. the harvested green crop is composted with straw, mud, river silt and farmyard manure in a compost pit which may be circular or trapezoidal. The materials are put into a compost pit layer by layer (15 cm thick) adding superphosphate after each layer (0.5 - 1%) and saturated with water. The last layer should be of silt. Sometimes, the composting is done by placing three layers (45 cm) of green manure crops, grass, silt mixture and farmyard manure into the pit in that order before sealing with silt. Water is poured over the silt up to a height of 5-6 cm. The composition and amount of the mixture in the pit are silt 7.5 tons, rice straw 0.15 ton, farmyard manure 1 ton, green manure 0.75 ton and 0.02 ton superphosphate.

The materials are usually placed in the pit in January and remain there for 2 to 3 months during which time they are turned over 2 to 3 times. The last turning over is done about 15 days before applying in the field;

v. the green crop is interplanted with rice and ploughed under before the second rice crop.

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Sesbania cannabina for example, is broadcast in the nursery at the rate of 84 kg/ha; after 50 days the young green crop is interplanted with early rice (summer rice: 2-3 m between rows; 30-35 cm between plants). When the plant attains a height of 100-120 cm, it is topped, and additional manure (75 kg of superphosphate and 2250 kg of compost/ha) is applied to the field ten days before harvesting the rice (that is 20 days after transplanting). Another manuring is done after rice harvesting (45-60 kg of ammonium sulphate per hectare) and Sesbania is ploughed under three to five days before the transplantation of the late rice. The yield of Sesbania is about 15 to 22.5 tons of green matter per hectare.

3. CITY GARBAGE

Domestic refuse is conveyed to collecting points from where it is collected by trucks, under management of the cleaning department and taken to the garbage treatment plants or directly to nearby communes for direct composting.

At the garbage treatment plants, the garbage, which is usually free from leather goods, bottles, tin and other non-decomposable materials, is tipped into a series of compost bins (fermentation tanks) constructed with bricks, with an addition of 12-15% of water by bin (capacity of each bin is about 11 m^3). Each compost bin has a small ventilation hole at its base, this hole is sealed with brick when the garbage is tipped in. The garbage is composted for about 25 days in order to kill fly ova and avoid multiplication of flies when applied to the fields. At this time the temperature in the bin reaches 72°C. Very often all parasites are destroyed in about 7 days storage. The compost of each bin is sold to the commune members who apply it to the field for ploughing under before cultivation.

The nutrient contents of the garbage is: organic matter 15-20%, nitrogen 0.37%, phosphorus 0.15% and 0.37% of potash.

In the commune, the garbage is delivered as heaps for compost and they are usually about 5 m in diameter and 2 m high, covered with a thin layer of silt or mud. The garbage is turned twice during the three months it stays on the ground and at the end of this time it becomes a brown friable material. To make it richer the garbage is sometimes mixed with pig manure or night-soil and the ratio of mixing with silt is 40% garbage plus night-soil or pig manure and 60% silt. Heaping is done under a roof in alternative layers; each layer is 10-15 cm high and the whole heap contains about 11 layers. One quarter kilogram of superphosphate is added to 50 kg of the garbage before processing.

In some communes, wheat and rice straw are mixed with garbage, silt and water. The mixture is made into a heap and covered with silt. If the temperature is high (summer), the mixture can be used after a short time, otherwise it will be turned over after 15 days and after one month it can be used.

Green manure crops, urine, human and animal excreta can also be mixed with garbage and water in the ratio of 1:1 and heaped in a built pit. The pit is covered by mud and fermentation takes place anaerobically.

The compost is used as a basal application to the soil at about 22.5 tons per hectare per year.

4. APPLICABILITY TO AFRICA

The way the Chinese recycle green manure crops and city garbage is simple but very efficient. Many of the green crops are well known in the African Region and vast quantities of data are available from experimental farms and stations concerning their use. The city garbage is collected every day in the towns or in the villages and is dumped at particular places for burning.

It would appear that the recycling of organic wastes in African agriculture means a complete change of the actual system. An international and regional approach would be desirable to consider the following:

i. the information available in the region about green manure crops, the quantities and methods of collection and disposal of city garbage in each region;

ii. the technicalities involved in their processing and how information on these may be obtained, and the possibilities for their utilization and adoption;

iii. the constraints to their application - the socio-economic aspects and the importance of animal/crop association;

iv. the transmission of experience obtained in one country to another in the same ecological zone;

v. the establishment of cooperation between the scientists within this Region and elsewhere, and the development of a team approach;

vi. specific research programmes could be identified at the national and regional level to stimulate agricultural development.

Paper 20

THE EFFECTS OF METHOD OF DUNG STORAGE AND ITS NUTRIENT (NPK) CONTENT AND CROP YIELD IN THE NORTH EAST SAVANNA ZONE OF GHANA

P.K. Kwakye [1]

Summary

Four methods of cow-dung storage: loose, compact, loose-compact and buried to assess their NPK contents were compared. The compact method was used in another experiment to evaluate the effect of addition of phosphates on N content of dung during storage. A 2^4 NPKD factorial experiment was also conducted on the "Varempere" soil series, an Eutric Nitosol, to study the responses of early millet interplanted with guinea corn and a pure stand of groundnuts to combined N, P, K and D (dung) applications.

Results showed the highest percent dry matter and N, P, K contents in the dung under buried and compact methods of storage. Greatest nutrient losses occurred when the dung was completely or partially exposed to direct sunlight and rain. The addition of phosphates significantly reduced N losses in the dung during its storage, single superphosphate being most effective due to its high sulphur content. Ten tons of dung per hectare had a significant effect on the yield of early millet interplanted with guinea corn and a pure stand of groundnuts. Application of well preserved dung may substantially increase crop yield in the north-east savanna zone of the country.

1. INTRODUCTION

With the present high cost of artificial fertilizers the use of local materials as fertilizers for maintaning soil fertility assumes great importance in the developing countries, where fertilizer industries are completely lacking or are in their initial stages of development.

Cow-dung is the main source of soil amendment used in some countries by most peasant farmers for improving soil fertility particularly within the savanna areas in the northern and upper regions of Ghana where cattle rearing is practised. Manure preservation and storage are however, not given the deserved attention. The excreta are usually exposed to direct sunlight and rains in the field due to the nomadic system of cattle rearing in the area with the result that considerable amounts of plant nutrients are lost through volatilization and leaching. Often, the manure is applied in such a dried state that little or no benefit is derived from its use.

Lynn (1937) reported the percent of NPK in a typical unpreserved cow-dung as 0.47, 0.36 and 0.79 respectively. However, the nutrient status was considerably raised when the dung was stored in pits of grass-cereal stalk bedding, the respective percent NPK contents being 0.68, 0.71 and 1.13. Percent nutrient contents of cow-dung samples from three agricultural stations in the interior savanna zone of Ghana ranged from 0.70-1.3% N, 0.55-0.74% P_2O_5 and 0.96-2.4% K_2O (Ofori 1962). Storing cattle manure in pits in Sudan, Musa (1975) found that the soluble nitrogen fraction was not only maintained but more nitrogen was solubilized after four months. Under proper conditions of handling and storage the nutrient status of animal manures can be improved to satisfy crop requirements for increased yields.

Methods of cow-dung storage aimed at minimizing nutrient losses and its application on crop yield formed the basis of these investigations.

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2. EXPERIMENTS

2.1 Materials and Methods

Experiments were conducted at the Manga Agricultural station in the north-east savanna zone of Ghana. Four methods of manure storage were studied, namely: a) loose, b) compact, c) loose-compact, and d) buried.

Loose method: The dung was loosely spread on a thick bedding of dry grass.

Compact method: the dung was spread in layers of about 30 cm thick and was compacted using wood.

Loose-Compact method: the first layer of dung was left loose for 3-5 days. It was then compacted and a second layer was added. Placement of dung and compaction continued until a height of 1 m was attained.

Buried method: the dung was stored in a pit measuring 1 m deep, 1.2 m long and 0.9 m wide. The heaps, with the exception of the loose method, were covered with thick layers of dry grass and soil and stored for three months.

Using an auger, five composite cow-dung samples taken at 20 cm intervals were collected for moisture, N, P and K determinations. Nitrogen was determined by the micro-Kjeldahl method, phosphorus by the ammonium molybdate-ammonium vanadate method and potassium by the dry ashing-flame-photometric method (Chapman and Pratt 1961).

2.2 Experiment 1

Investigations were conducted to evaluate the effect of the addition of phosphates on the nitrogen content of dung during storage. The compact method of storage was employed with additions of single superphosphate, triple superphosphate and rock phosphate corresponding to 3% of the weight of dung. The dung heaps were stored for three months and sampled as described above for dry matter and nitrogen determinations.

2.3 Experiment 2

A 2^4 NPKD factorial experiment with two replicates was established to study the effect of combined mineral fertilizer and organic manure application on crop yield. Early millet interplanted with guinea corn was rotated with groundnut in this experiment.

Each plot measured 10.6 m x 9.0 m. Sulphate of ammonia, single superphosphate and muriate of potash at the rates of 67 kg N, 33 kg P_2O_5 and 33 kg K_2O per hectare respectively were applied to each plot. Dung stored for three months and containing 23% dry matter, 1.37% N, 0.63% P_2O_5 and 1.96% K_2O at the rate of 10 tons/ha was broadcast and incorporated into the soil by hoeing two weeks before planting. Local varieties of early millet and guinea corn were interplanted in the middle of May and a groundnut variety (Spanish 207/3) in June. All the phosphate and potash, and 2/3 of the nitrogen were applied in rings two weeks after germination of the cereals. The remaining 1/3 nitrogen was applied to the guinea corn after harvesting the early millet. Groundnut plots received 20 kg N, 40 kg P_2O_5 and 10 kg K_2O per hectare broadcast and hoed into the soil at planting. Nitrogen was applied in the first cropping season.

The average annual rainfall at the station varies from 965 mm to 1 092 mm. The soil, a savanna ochrosol developed over residual sandy clay derived from weathered biotite granite, is classified according to the FAO-Unesco system, as Eutric Nitosol. Chemical characteristics of the 0-40 cm layer are shown in Table 1.

Table 1 CHEMICAL CHARACTERISTICS OF SOIL

Depth cm	ph	ppm P	ppm K	%O.M.	%N	CEC	Ca	Mg	K
							meq/100 g soil		
0-20	6.3	11	21	.60	.042	2.61	1.27	.39	.23
20-40	6.2	9	23	.47	.028	3.72	1.46	.68	.15

2.4 Results and Discussion

Results of cow-dung analysis presented in Table 2 indicated that a higher percent dry matter, nitrogen and phosphorus were found in the dung under buried and compact methods of storage.

Table 2 THE EFFECT OF METHODS OF STORAGE ON N, P AND K CONTENTS OF COW-DUNG

Method of storage	%			
	Dry matter	N	P_2O_5	K_2O
Loose	22	.71	.50	1.32
Compact	26	.93	.51	1.51
Loose-Compact	24	.79	.55	1.45
Buried	27	1.48	.60	2.14
L.S.D. (P = .05)		.36	.07	.00
L.S.D. (P = .01)		.51	NS	.11

The original sample contained 69% moisture, 1.74% N, .67% P_2O_5 and 2.40% K_2O. When the dung was completely or partially exposed to direct sunlight and rains, the percent nitrogen and potassium were considerably reduced. The difference between percent N content in the dung in the buried and the other three methods of storage was highly significant. Percent P_2O_5 content in the buried method was significantly higher than in the loose and compact methods at the 5% level. Differences in K_2O contents between the four storage methods were highly significant.

Greatest dry matter and nutrient losses, particularly nitrogen and potassium, occurred under the loose and loose-compact methods of storage due possibly to a faster rate of decomposition of dung and mineralization of nitrogen resulting from better aeration and high temperatures (Table 3).

Table 3 LOSS OF NUTRIENTS DURING 3 MONTHS STORAGE RELATIVE TO ORIGINAL SAMPLE

Method of storage	%			
	N	P_2O_5	K_2O	Dry matter
Loose	59.2	28.3	45.0	28
Compact	46.6	26.7	37.1	16
Loose-Compact	54.6	20.0	39.6	22
Buried	14.9	11.7	10.8	12

Volatilization of ammonia and leaching are other factors leading to nutrient losses of manures during storage. The loss of nitrogen in cattle manure in the form of ammonia has been established by some authors (Lynn 1937; Klechkowskii and Peterburgskii 1967).

The least dry matter and nutrient losses found in the dung which was buried could be attributed to the rate of decomposition under anaerobic condition.

Table 4 gives the results of analysis of dung treated with three types of phosphates. It is shown that single superphosphate, triple superphosphate and rock phosphate significantly reduced nitrogen losses of the dung during its storage (P = .01). Nitrogen content of the dung without phosphate treatment was reduced from 1.74% to 0.87%, amounting to 50% of its initial content.

Table 4 EFFECT OF ADDITION OF PHOSPATES ON % N CONTENT OF COW-DUNG STORED FOR 3 MONTHS

Treatment	N	% N increase
Dung + no phosphate	0.87	---
Dung + single super phosphate	1.50	73
Dung + triple super phosphate	1.04	21
Dung + rock phosphate	1.29	49
S.E.	±0.028	
L.S.D. (P = .01)	0.09	

The addition of phosphates to the dung might have activated microbiological processes, creating favourable conditions for binding the volatilizing nitrogen into the microbial plasm.

Comparing the three sources of phosphates, single superphosphate was the most effective agent for increasing nitrogen content in the dung and rock phosphate was superior to triple superphosphate. The superiority of single superphosphate in increasing nitrogen content in the dung may be due to the high sulphur content. Calcium sulphate possibly combined with the liberated ammonia gas (NH_3) from the dung to form ammonium sulphate. The effect means of combined NPK fertilizers and cow-dung application on early millet interplanted with guinea corn and pure stand of groundnuts are presented in Table 5.

Table 5

MEAN EFFECT OF COMBINED NPK FERTILIZERS AND COW-DUNG APPLICATION ON EARLY MILLET AND GUINEA CORN INTERPLANTED AND GROUNDNUT, KG/HA

Treatment	1973			1974			1975			1976		
	G'nut	E. millet	G'corn	G'nut	E. millet	G'corn	G'nut	E. millet	G'corn	G'nut	E. millet	G'corn
Mean Yield	956.2	576.1	321.7	936.2	1869.8	491.3	679.8	1345.8	554.1	705.0	1033.1	388.9
N	21.3	289.2**	104.2**	102.0*	641.3*	323.2**	-23.7	400.1**	634.1**	-130.8	224.1**	67.7
P	96.4	122.2*	51.6	83.1	106.2	30.5	39.9	176.8	140.5*	191.1**	-50.3	-8.7
NP	-4.5	49.3	66.1*	79.4	79.5	116.9*	-9.2	-92.1	62.4	-15.9	164.8*	50.3
K	4.5	69.5	-33.6	20.1	67.5	-8.5	-61.4	21.5	42.7	-131.2	-7.1	7.1
NK	129.1	-12.3	-3.4	10.9	23.7	-4.4	2.4	-27.1	-28.6	-21.3	-45.6	-7.0
PK	113.2*	32.5	13.4	57.8	69.7	-61.2	51.7	27.3	-40.3	59.7	-6.9	3.5
NPK	12.3	41.5	-29.1	87.9	-35.5	-77.8*	35.3	46.7	-99.0	-21.9	147.7	53.8
D	84.1*	81.8	61.6*	96.1*	347.6	207.4**	235.7**	445.5**	330.9**	130.2	208.8*	67.8
ND	-16.8	-16.8	19.1	38.6	-51.1	19.8	21.2	72.8	111.0	-70.8	112.9	38.1
PD	100.9*	-20.2	-38.1	13.7	-12.9	-12.5	37.7	-116.8	-113.8	-21.9	1.6	-13.9
NPD	-67.3	-61.6	-31.4	7.8	143.3	20.5	16.5	-186.4	-152.7*	-125.4	-131.8	-46.8
KD	41.5	32.5	3.4	-45.2	136.3	38.1	-16.5	-16.7	8.7	11.1	-102.3	-17.3
NKD	41.5	32.5	49.3	4.6	210.6	41.2	28.2	-31.4	-50.1	59.7	66.1	36.5
PKD	-24.7	-37.0	29.1	60.6	-119.4	28.5	30.4	-71.3	33.0	43.2	38.2	15.6
NPKD	9.0	-44.8	3.4	13.2	22.3	29.5	23.5	51.1	8.8	38.1	-227.4**	-72.9
S.E.	±39.2	±57.2	±26.9	±41.5	±223.8	±30.2	±52.9	±131.0	±65.3	±63.3*	±76.8	±35.6
L.S.D. 5%	84.1	122.2	58.3	88.3	476.9	64.2	112.8	279.2	139.2	135.0	163.6	75.8
L.S.D. 1%	NS	169.3	80.7	NS	NS	88.9	156.0	386.1	192.2	186.5	226.3	NS

Consistent highly significant effect means of nitrogen application at the rate of 67 kg/ha on early millet interplanted with guinea corn have been observed. In the first cropping season, the effect of nitrogen on groundnut was not remarkable. In the next season, when groundnut followed early millet interplanted with guinea corn, the residual effect of nitrogen on the kernel yield was significant (P = .05). In the subsequent years (1975, 1976) no residual effect of nitrogen on groundnut was obtained. The lack of response of groundnut to the residual nitrogen might be due to removal of large amounts of the nutrient by the early millet and guinea corn which yielded highest in 1974 and 1975. It is therefore suggested that a starter nitrogen at the rate of 10 - 20 kg N per hectare should be applied to groundnuts following early millet interplanted with guinea corn.

All the test crops markedly responded to phosphorus application, the effect means being significant on early millet in 1973, guinea corn in 1975 (P = .05) and groundnut in 1976 (P = .01). Nye (1953) obtained large responses of the same crops to the application of 67 and 134 kg single superphosphate in the Bawku area. The effect means of NP treatment were more pronounced on guinea corn, whilst groundnut usually responded negatively.

Potassium applied alone and NK application did not have any significant effect on crop yield, but PK fertilization showed a positive effect on groundnut. Cow-dung applied at 10 tons/ha showed significant effect means on guinea corn and groundnut for the first three cropping seasons (1973 - 1975), with responses being highly significant in 1975 for all the three crops. The response of early millet to dung application steadily increased and reached statistical significance at the 1% level in 1975. In the following year, crop yields were adversely affected by severe drought which persisted during the cropping season. However, the mean effect of dung on early millet was significant and the effect on guinea corn and groundnut was close to significance at the 5% level. The responses of crops to dung application in this experiment confirm the results obtained by previous researchers (Lynn 1937; Nye 1953; Nye and Stephens 1962; Sargion 1960) in the same area. Similar responses have been reported by Obi (1959) applying 2.5 tons manure per hectare to early millet and guinea corn interplanted, and groundnut in Northern Nigeria. With the exception of P x D interaction, which had a significant effect on kernel yield of groundnut in the first season, all N, P, K x D interactions showed no significant effect on crop yields. It appears that amounts of N, P, K released from the dung were sufficient to satisfy the plants' requirements and additional N, P and K application did not therefore contribute positively to the nutrition of the local unimproved millet and guinea corn.

Employing the compact or buried method of manure storage with the addition of phosphates, cow-dung application at the rate of 10 tons/ha may substantially increase crop yields in the north east savanna zone of Ghana.

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Paper 21

EXTENSION AND TRAINING

H.O. Mongi [1]

Summary

A proposal is made that the large quantities of valuable organic materials available in developing countries be more fully utilized as alternatives to expensive inorganic fertilizers, soil conditioners, and fossil fuel. More serious and concerted efforts in programme planning and implementation are called for. A well integrated manpower training and extension programme is conceived as a key strategy to the success of a national programme for the utilization of the organic materials resource. The wider support for a programme to create an organic materials industry, directed at agriculture, should result in a higher national gross product and a lower national debt consequent upon less dependence on imported fuels - for farm energy - and inorganic fertilizers.

1. INTRODUCTION

The present world energy crisis and its effects on both fertilizer prices and availability, as well as on farm energy, makes it necessary that we turn to and give a higher priority to the better utilization and development of organic materials as alternative sources of plant nutrient elements, soil conditioners/amendments, and farm energy. It is equally necessary that we make increased and fuller use of all farming systems which result in improved soil fertility and productivity, increased food and fibre production, thereby bringing greater economic prosperity, especially for the developing countries.

Agricultural production, generally and per unit basis, in much of the Third World is presently quite low due to inadequate deployment of human and material resources and also inadequate utilization of appropriate and already available production technology. The challenge for sustained and increased production off the land is being met by developing countries against many odds. These countries have been primarily engaged in the building up of the institutional organizations essential for the guidance of national development programmes, particularly the national educational institutions, in a manner which best suits their current social, political, and economic situations.

The rural populations are largely illiterate and the national governments cannot yet provide enough well-trained technicians and professional staff to lead effective agricultural extension programmes. Neither are the countries yet training enough professional or technical agricultural cadres because of:

i. inadequate facilities for manpower training;

ii. poor manpower planning and manpower development strategy;

iii. the inability of the national organs or treasuries to pay the salaries of more than a certain number of cadres annually, and

iv. insufficient appreciation of the big role which agriculture can play in the nation's economy and, thus, the need for its appropriate and deliberate planning as an industry for the realization of higher capital formation.

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The few staff which most of these countries could afford to employ had, necessarily, to be trained so as to be able to handle either the requirements of certain specialist cash crops, or a great variety of the more serious crop or animal husbandry problems.

Some farming systems of the Third World use quite substantial amounts of organic materials (Nye and Greenland 1976; Stephens 1970; Tothill 1948). However, the training of agriculturists in much of the Third World was not constrained to pay particular attention to the technology required in the utilization of organic materials in agriculture, particularly as land for further expansion, shifting cultivation, or fallow was plentiful (Nye and Greenland 1960; Stephens 1970). Training programmes generally mentioned these organic materials and covered their physical and chemical effects on soil properties. Actual practical training in the collection, handling, processing, transportation, storage and application of the various organic materials was not normally offered.

Efforts made in the recent past to popularize the increased use of organic materials in agriculture have not paid off well because of:

a. handling or processing problems and the relative non-availability of some of the materials on some farms;

b. inadequate knowledge on the part of the farmers on the benefits and application methods for available materials;

c. lack of well designed extension programmes for the popularization of their use, and

d. general lack of re-training programmes to up-date the knowledge of extension personnel and to prepare them for action in a well planned and organized extension programme.

There is now urgent need for serious and concerted national efforts to use organic materials more fully for partial or full replacement of expensive inorganic fertilizers, and as soil conditioners, or sources of farm energy. These materials are inadequately and/or inefficiently utilized. Estimates (Aldrich 1972; IBRD 1973) are that the main organic materials which will become available in developing countries as "wastes" will have an NPK value of about US $20 218 million (at 1973 world fertilizer f.o.b. prices), equivalent to about 60, 20 and 49 million tons of N, P and K respectively. Poor countries can hardly afford to waste resources worth so much money and instead borrow high interest funds from credit banks abroad.

2. EXTENSION STRATEGY

The world is now faced with high costs of agricultural inputs and a serious shortage of food and fibre. In particular the costs of fertilizer are presently very high and the procurement of fertilizer is not always within easy reach of most farmers. Besides, most farmers in developing countries have little money that can be spent on the purchase of fertilizers; and their credit-worthiness is poor. Resort to use of organic materials as sources of fertilizer, and as a means of improving the physical-chemical and biological condition of the soil is the alternative.

The extension effort which seems to be appropriate for adoption by national governments needs to include the following:

i. nation-wide training and education of all farmers in those aspects of handling, processing, transportation, and application of organic materials in which they should be knowledgeable at the farm level;

ii. setting up of demonstrations on the processing and application of organic materials at selected regional, district, or village centres;

iii. popularization of suitable bio gas plants and the encouragement of their local manufacture so as to reduce dependence on other fuels;

iv. establishment of training programmes for extension workers on the efficient use of organic materials in agriculture, based at schools, institutes, colleges, and universities;

v. preparation of suitable audio-visual aids and reading materials for use by mass literacy campaigns, farmers, extension workers, and the mass-media;

vi. ensuring that farmers always use the most efficient nitrogen-fixers in crop rotations, mixed cropping, intercropping, and green manuring practices; and

vii. the setting up of industrial waste and municipal refuse processing and/or composting plants along with a programme for the utilization of their products, geared to the development of intensive agriculture in the peripheral areas of the municipality, initially on a trial basis.

3. EDUCATION AND TRAINING

Investments in education and training are vital to the success of any development programme. Progress in the greater use of organic materials in agriculture may be considered to have been militated mainly by ineffective education and specific training programmes.

Farmers in tropical and subtropical areas will be putting greater dependence on organic materials as fertilizers and as sources of farm energy. Hence, the manpower required to service the related agricultural extension needs must be more capable both in terms of quality and quantity.

The most immediate action that can be foreseen as an aid to extension and training is as follows:

i. increase the capacity of the extension service through the provision of more technical and professional cadres specially trained in the use of organic materials as fertilizers;

ii. restructure all training programmes in agriculture (and related fields) at all levels, as appropriate, to provide both theory and practical instruction in the principles, collection, processing, storage, transportation, distribution, and utilization of organic materials (farm manures, composts, crop residues, mulches, forest litter, moss and peats, municipal and industrial wastes, cover and rest crops, legumes, nitrogen fixation, green manuring, mixed cropping and inter-cropping); in this regard expand sub professional training to include the award of higher national certificates and diplomas;

iii. provide for the conduct of specific organic material studies as part of the university high level manpower training strategy, in research methodology, which should also include nitrogen fixation (as at the MIRCEN and IITA), N-lignin, nitrification inhibitors, use of organic materials in fertilizer bulk blending, and the evaluation of the social, economic and other factors involved in the collection, processing, transportation, storage, and utilization of organic materials in agriculture;

iv. preparation of suitable practical manuals on the use of organic materials, as training aids;

v. making available all research findings and publications on the use of organic materials in agriculture, or lists thereof, for the use of trainers and trainees;

vi. organization of seminars or colloquia on crucial issues in the utilization of organic materials, which should involve extension, training, research, and agricultural planning personnel, as an aid to faster take-off in their use;

vii. seek, or offer, fellowships on the handling, processing and utilization of organic materials in agriculture, tenable both within and outside the national countries; and

viii. establish, in the national universities, units attached to the agricultural faculties, to serve as 'centres of excellence' for interdisciplinary organic materials studies, including social and psychological issues affecting their use, which units may also be used for related in-service courses and conferences;

ix. organize refresher courses for all staff expected to lead programmes involving the use of organic materials in agriculture; and

x. offer attractive job opportunities with good salary structures, housing, transport, and fringe benefits (as incentives), so as to attract a suitable number of good candidates for training and employment in agricultural disciplines.

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APPENDIX I

PROGRAMME

Monday 5 December

Opening Session and Registration

Tuesday 6 December

09.00 - 12.30

1. Cameroon Country Report
   E.M.T. Awa

2. Current practices of organic recycling by Kenyan farmers
   J.N. Quereshi

3. The use of organic materials in increasing crop production in Africa
   C.S. Ofori

14.30 - 18.00

4. Organic recycling in Asian agriculture
   A. Singh and V. Balasubramanian

5. Crop residue management and soil productivity in the savanna areas of Nigeria
   L.A. Nnadi and V. Balasubramanian

Wednesday 7 December

09.00 - 12.30

6. Cropping systems and soil burning in Cameroon and their influence on organic matter recycling in agriculture
   S.N. Lyonga

7. The effect of various types of mulches on soil moisture in a coffee field at Kabete, Kenya
   S.O. Keya

8. Results of experiments on legume inoculation and N_2 fixation in Zambia
   M.N. Zayed

14.30 - 18.00

9. Some microbiological and chemical effects of the decomposition of crop residues in irrigated Sudan soils
   M.M. Musa

10. Effect of nitrogen fertilization (urea) and of organic amendments (compost) on the productivity of a soil and the stabilization of organic matter in a millet monoculture in semi-arid tropical conditions
    F. Ganry and C. Feller

11. The effect of edaphic factors on N_2 fixation
    Y.R. Dommergues (given by M.N. Zayed)

Thursday 8 December

08.30 - 12.30

12. Review of cropping systems in relation to crop residue management in semi-arid zones of West Africa
    J. Poulain

13. Effects of different cropping systems on soil fertility management in the humid tropics of Africa
A.A. Agboola

14.30 - 18.00

14. Interaction between farmyard manure and NPK fertilizers in savanna soils
U. Mokwunye

15. The effects of the method of dung storage and its nutrient content on crop yield in the northeastern savanna zone of Ghana
R.K. Kwakye

16. Case studies on organic recycling in Kenya
S.M. Mugambi

17. Extension and training
H.O. Mongi

18. The activities of FAO in the field of biological N_2 fixation
H. Braun

Friday 9 December

08.30 - 12.30

19. Effects of straw application on the fertilizer needs of a sorghum-cotton rotation in North Cameroon
J. Gigou

20. FAO Technical Cooperation Programme
H. Braun

14.30 - 18.00 Working groups

Saturday 10 December

Excursion to the Cameroon Development Corporation's estates - (tea, rubber, oil palm, pepper and banana).

Monday 12 December

08.30 - 12.30

21. Organic matter and the study of soils in the field
G.W. van Barneveld

22. Learning from China: upland green manuring and recycling of city garbage, and opportunities for international and regional cooperation in recycling of organic wastes in agriculture
R. Sant'Anna

23. The potential contribution of nitrogen from rhizobia
A. Ayanaba

24. The importance of cultural methods for increasing the quantity of nitrogen fixed by groundnut crops in the Sudano-Sahelian zone of Senegal
F. Ganry

14.30 - 15.30 Working groups

19.00 - 22.00	25.	Crop residue management in relation to tillage techniques for soil and water conservation and management R. Lal
	26.	A review of cropping systems in relation to crop residue management in the humid tropics of Africa B.N. Okigbo

<u>Tuesday 13 December</u>

08.30 - 12.30	27.	Research needs D.J. Greenland
		Working groups
14.30 - 15.30		Plenary Session and Recommendations
16.00		Closing Session

APPENDIX 2

LIST OF PARTICIPANTS

A. Participants

J.M. Acheampong	Regional Agricultural Officer Ministry of Agriculture Box M 37, Accra, Ghana
A.A. Agboola	Department of Agronomy University of Ibadan Ibadan, Nigeria
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M.N. Zayed	Professor, Soil Microbiology R.H. Makulu Research Station P.O. Box 7, Chilanga, Zambia

B. Observers

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L. Ngonda	Chief of Sector Ministry of Animal Breeding and Industries Buea, Cameroon
Y.S. Puh	Agronomist, Project FAO-LIR/73/012 c/o UNDP, P.O. Box 274, Monrovia Liberia
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STATEMENTS

1. Opening Address by B. Ly, SAA/FAO Country Representative

The energy crisis prevailing since 1973 continues to disorganize world economy. The world's agriculture has not been spared in this disorder. Unfortunately, the developing countries are paying a heavy tribute to that and among them, African countries are no doubt the most affected by this energy crisis in their agriculture. The repercussions have been strongly felt in the development of agriculture due to the high costs of agricultural inputs like fertilizers, pesticides, etc. Therefore, it has been felt necessary to try to lessen the effect of chemical fertilizer costs in the agriculture of the Third World. One solution would be: the utilization of organic matter in the development of agriculture. In this context, FAO organized a study tour in China, in April - May 1977, in order to acquaint agricultural technicians of the developing countries with Chinese techniques in organic recycling. One high level Cameroon technician has participated in that study tour to China and has made some interesting suggestions in his report. It is hoped that African countries will profit from Chinese experience.

The purpose of this Workshop is to draw our attention to interest in the utilization of organic matter in agriculture.

I would take this opportunity to express, on behalf of its Director-General, FAO's gratitude to the Government of the United Republic of Cameroon and to its prestigious President, His Excellency, Ahmadou Ahidjo for all facilities put at our disposal for the purpose of this African meeting. We also thank SIDA, the Swedish International Development Authority, which has financed this Workshop.

I am sure that you will achieve very good work because you are being placed in the best material conditions by the Government of the United Republic of Cameroon.

2. Address by Fon Fosi Yakum-Ntaw, Governor of the South West Province

I have the honour to welcome to the United Republic of Cameroon in general and the South West Province in particular, all participants who have come from the different brotherly countries to take part in this ten day seminar on Organic Recycling in Agriculture. We are highly honoured that Buea has been chosen as the venue for the seminar and we hope that you will find the choice quite suitable not only for your deliberations but also for your personal relaxation. On our part, we want to assure you that you are all very welcome in our midst and that you should feel completely at home here.

This conference brings together some 45 Agricultural Scholars, Scientists and Technicians from 16 countries, namely: Botswana, Ethiopia, Gambia, Ghana, Kenya, Lesotho, Liberia, Malawi, Mauritius, Nigeria, Sierra Leone, Swaziland, Tanzania, Uganda, Zambia and Cameroon, who will in the course of the next ten days put their heads together, exchange ideas, compare the results of their respective scientific investigations and generally discuss their experiences in the field of Organic Recycling in Agriculture with a view to providing mankind with better means of fighting against hunger and malnutrition. This has been made possible thanks to the joint sponsorship of the Food and Agriculture Organization of the United Nations (FAO) and the Swedish International Development Authority (SIDA). We take this opportunity to express our sincere thanks to both organizations for making this laudable effort to improve the lot of humanity especially in the developing countries. We wish to thank also all participants and their respective Governments for the effort they have made to make the present seminar a reality.

The fight against underdevelopment is long and exacting but necessary and urgent. Development is increasingly concerned with meeting the basic needs of the world's growing population. This concern arises from realistic human values which recognize that man is the measure of all things and that, therefore, development should be for the betterment of man.

History tells us that no great civilization or empire is known to have developed without good soil and water and that most of these civilizations lasted only as long as the soil remained productive and water was available. Consequently, both good productive soil and water are vital resources which must be properly managed and conserved in order to serve not only present but also future generations.

The problem of hunger has remained the biggest human problem since our creation. Some of the early migrations of populations took place under the compulsion of food scarcity and the need to explore fresh food sources. There is no period in history when the entire population has been free from hunger and malnutrition. Today, in spite of all the advances in science and technology and progress in international cooperation that have opened up incalculable opportunities for human betterment, the ills of hunger remain constantly with us.

The resources of the developing countries and particularly the African continent are enormous. We are optimistic about the capacity of our countries to climb out of primary poverty, ignorance, illiteracy, hunger and malnutrition. There is presently an upward surge in this direction in the population of the world at an unprecedented rate. Our resources are continually being devastated and taxed to produce at an all-time record pace. You, as scientists, are called upon at this seminar to examine, compare notes and findings and come up with better ways of manipulating the soil resources, to halt its deterioration and increase its prospects for greater productivity. You will examine recommendations concerning some of the means that are considered likely to ameliorate the soil for greater productivity.

Thanks are due to the Food and Agriculture Organization for its continuous desire to keep our minds constantly awake to the problems of agriculture. Thanks also to the Swedish International Development Authority for its continuous assistance in the war against hunger. One man's freedom from hunger and want is not true and secure until all men are free from hunger and want. Our knowledge of agricultural problems is mostly the result of experience and research in temperate countries. This is why our Research Institutions are being called upon to devise formulas to solve pertinent problems in our own agricultural development.

The Government of the United Republic of Cameroon will be greatly interested in the result of your deliberations and will consider very carefully what recommendations you will make at the end of this session. Already His Excellency Ahmadou Ahidjo, President of the United Republic of Cameroon, used the opportunity offered last month by the national agro-pastoral show which took place in Bafoussam in the West Province to re-iterate the necessity for Agricultural Scholars, Technicians and Scientists to study very closely the basic practices of our farmers so that their proposals for introduction of new systems can be easily compatible and acceptable to these farmers. The local farming practices have evolved through years of experience, trial and error and hardship, and contain a lot of ingenuity. While inventing and introducing scientific farming practices, we must safeguard our ecological balance. You are here charged with the task of planning agricultural exploitation with the minimum of wastage. You have to think and find means of utilizing some of our waste products for the betterment of mankind.

We must not fail to realize that agriculture is still the main economic activity in most of Africa. It provides a way of life to the largest sector of our population. The land has been and will continue to be the chief source of savings and capital accumulation for the development of other sectors of the economy. The Food and Agriculture Organization has a long record of effort in focusing public attention on the nutritional state of the world and stimulating public discussion on the ways and means in which governments, people and international organizations could cooperate to bring relief to millions of hungry, and under-nourished people in the world. The Freedom from Hunger Campaign has created an awareness and need for the usefulness of fertilizers in all parts of the globe. Despite the national and international efforts of the past decade, progress towards a total elimination of hunger and poverty has been slow.

Our efforts in this direction are constantly being examined and renewed where necessary as a result of seminars and conferences of top scientists of your calibre. We believe that the participating countries are all anxiously awaiting the result of this seminar.

Considering the importance to all developing countries, in particular the humanitarian nature of your work, and in considering the many technical papers to be presented and submitted to your critical examination, I do not wish to take any more of your valuable time. Accordingly, I sincerely wish you every success in your deliberations.

With these few words, Ladies and Gentlemen, I declare open this seminar on Organic Recycling in Agriculture.

3. Address by the Secretary General to the Governor, Mr. Simon Tabe, at the Closing of the FAO/SIDA Workshop

It is a very great pleasure for me, on behalf of the Honourable Minister of Agriculture, who is otherwise engaged, to be among you at the closing session of the ten day Regional Workshop on Organic Recycling in Agriculture. Once again, I wish to state that we are highly honoured that Buea in the South West Province was chosen as the venue for the seminar and we hope that you have found this choice suitable for both your deliberations and personal relaxation.

This seminar, which brings together members from such distant and varied countries on the African continent and Europe, demonstrates the importance you as individuals, members of respective nations or international organizations attach to the subject under consideration, namely, the conservation of soil fertility. You have in the last ten days exchanged ideas, compared the results of your respective scientific investigations and discussed generally your experiences in the field of Organic Recycling in Agriculture with a view to improving the lot of humanity against the unceasing misery of hunger and malnutrition. Our gratitude and thanks go to the joint sponsorship of the Food and Agricultural Organization of the United Nations and the Swedish International Development Authority. We wish also to thank all the participants and their respective Governments for their effort to make the present seminar a success.

The decade of the sixties saw the struggle of many African countries for independence from their respective colonial regimes. Having thus gained political independence, the struggle for economic independence, economic emancipation has continued and invariably with few exceptions most countries have adopted the system of systematic planning. Economic plans have been drawn up with a view to directing and controlling growth in important sectors. A contemporary survey of African Economics by the end of 1975 concluded that in spite of the willingness and efforts made by African States in the fight for economic and social development, it is to be noted that, in the aggregate, the results registered by each of them, remain modest.

The current decade of the seventies, which could be rightly termed the consolidation decade, must aim at providing a reasonable growth rate based on improved infrastructure coupled with proper land and water utilization. Also this decade, drawing a lesson from the past, must draw on a deep mastery of developmental techniques and on an irrevocable commitment of all the peoples concerned. In this direction, land remains our most valuable asset and its proper utilization for agriculture an indispensable tool. Agriculture in turn is dependent to a great extent on the fertility of the soil and it is in this sphere that the present seminar assumes prominence.

I have learnt with great satisfaction of the achievements at your seminar. The management of crop residues on the farms as mulches or as animal feed will surely need study and attention in all agriculture-dependent countries.

Your recommendations will go a long way to helping African governments draw up a comprehensive policy on the use of household garbage and other wastes that are so far looked upon as a nuisance and waste. I agree with you that the term "waste" is relative. What is waste under one condition may be of great value under a different situation. Our level of knowledge and technology will determine when the left-over materials and by-products of our environment are discarded as wastes. With the constant advances in science and technology, we look forward to a period when there will be no wastes in our society; all our by-products will be so well recycled that in every sphere no wastes will be left.

Our search for knowledge must be accelerated. To be capable of exploiting our vast tropical resources, to up-lift our countries out of poverty, ignorance, illiteracy, hunger and malnutrition, we must hasten our training projects at all levels. The peasant farmer needs some basic skills in all fields of production to be a viable farmer. Our countries need specialists to direct and advise our governments on the recycling of organic materials, as well as to conduct essential research on better and new methods of utilizing by-products of our industries and homes. I have come to realize that only the African can spearhead programmes to save himself from poverty and hunger, but international cooperation will help him towards this goal.

In my opening address on Monday, 5 December 1977, I stressed the necessity for agricultural scientists to study very closely the basic practices of our African farmers. I will still emphasize that it is essential not only to study these cultural practices of our farmers but also the importance of safeguarding our ecological balance in all agricultural exploitations.

The soil improvement capabilities of our tropical legumes demand further investigations. Legumes contribute greatly to our protein needs and maintenance of soil fertility.

I thank again the Food and Agriculture Organization of the United Nations for its continuous desire to organize seminars of this type and express my appreciation to the Swedish International Development Authority for the financial and technical assistance to projects that affect man's basic needs.

International cooperation of this nature brings together top scientists from the university campuses, research organizations, and policy makers of our Governments. Men who are moved by good will, generosity and the desire to lead developing nations to progress towards the well-being and dignity of man. Only action of this nature will lead to understanding and respect between nations, giving true meaning to human solidarity. With these words, Ladies and Gentlemen, I declare closed this seminar on Organic Recycling in Agriculture.

4. Closing Address by B. Ly, SAA/FAO Country Representative

It was a week and a half ago that we gathered here for the opening of the Workshop on Organic Recycling in Agriculture. During this period, we have been listening to and discussing many interesting technical papers. It was also a unique occasion for some of us to meet colleagues from various countries and to exchange experiences and ideas in our field of work. The keen interest shown by all participants during this Workshop reflects the importance we all attach to the theme.

On behalf of the Director-General of the Food and Agriculture Organization, I should like to thank once again the Government of the United Republic of the Cameroon and the authorities of the South West Province for all the facilities placed at our disposal and the warm hospitality extended to us. Our thanks also go to the staff of the Pan African Institute and the management of the Cameroon Development Corporation (CDC) for their assistance and hospitality. Finally, I should like to thank most sincerely the Swedish International Development Authority (SIDA) for the generous financial support for this Workshop.

It is our hope that the recommendations and ideas developed in this Workshop will be given serious consideration by our governments and research institutions so as to promote agricultural development thorughout Africa.

I should like to take the opportunity to wish all participants a safe return to their various countries.