SYSTEMS DEVELOPMENT IN AGRICULTURAL MECHANIZATION WITH SPECIAL REFERENCE TO SOIL TILLAGE AND WEED CONTROL

A case study for West Africa

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(with a summary in Dutch)

PROEFSCHRIFT
TER VERKRIJGING VAN DE GRAAD
VAN DOCTOR IN DE LANDBOUWWETENSCHAPPEN
OP GEZAG VAN DE RECTOR MAGNIFICUS
DR. IR. J. P. H. VAN DER WANT
HOOGLERAAR IN DE VIROLOGIE
IN HET OPENBAAR TE VERDEDIGEN
OP WOENSDAG 15 SEPTEMBER 1976
DES NAMIDDAGS TE VIER UUR IN DE AULA
VAN DE LANDBOUWHOGESCHOOL TE WAGENINGEN

H. VEENMAN & ZONEN B.V. – WAGENINGEN – 1976

STELLINGEN

1.

Mechanisatie, zoals gedefinieerd in dit proefschrift, is een essentieel onderdeel om de voedselproduktie te verhogen.

2.

Selektieve mechanisatie kan in belangrijke mate bijdragen om de landbouw attraktiever te maken en om tot een afname van de migratie naar de grote steden te komen.

B. A. Stout and C. M. Downing, 1974. Selective mechanization: a hope for farmers in developing countries. A.M.A., Summer, p. 13–17

3.

Mechanisatie met motorische kracht kan slechts met succes worden toegepast als aan een groot aantal andere voorwaarden is voldaan en is daarom in een vroeg ontwikkelingsstadium van de landbouw niet van het eerste belang.

Dit proefschrift

4.

Het energievraagstuk mag niet van doorslaggevende betekenis zijn voor het invoeren van mechanisatie in ontwikkelingslanden.

5.

Het moet ten zeerste betwijfeld worden of mechanisatie in West Afrika in de komende jaren zal leiden tot een vermindering van de werkgelegenheid.

6.

De vierwielige trekker verdient in West Afrika in het algemeen de voorkeur boven de tweewielige trekker.

Dit proefschrift

7.

Onvoldoende bodemonderzoek vooraf is veelal mede oorzaak geweest van het mislukken van mechanisatie in ontwikkelingslanden.

8.

Grondbewerkingsbehoeften kunnen voor een belangrijk deel afgeleid worden van profielbeschrijvingen en profielonderzoek onder natuurlijke omstandigheden.

Dit proefschrift

9.

Exploitatie van hydromorfe gronden dient krachtig gestimuleerd te worden in West Afrika.

10.

Onkruidbestrijding met de hand en de hak zal ernstige problemen blijven stellen om tot een groter verbouwd areaal per man te komen. Bij het bestuderen van alternatieve bestrijdingsmethoden dient de nadruk te liggen op mechanische onkruidbestrijding.

11.

Bij het bestuderen en invoeren van nieuwe bedrijfssystemen in de landbouw dient terdege rekening te worden gehouden met de agrologische selektie zoals die door de traditionele boeren is gedaan.

12.

Het valt te verwachten dat meer mogelijkheden tot het volgen van algemeen vormend onderwijs in Nigeria, in het bijzonder op het platteland, zal leiden tot een grotere migratie naar de steden.

H. A. OLUWASANMI, 1975. Effects of farm mechanization on production and employment in Nigeria. Meeting of the FAO/OECD expert panel on the effects of farm mechanization on production and employment, Rome, Italy, 4–7 Febr.. FAO, Rome, p. 51–70

H. P. F. CURFS
Wageningen, 15 september 1976

VOORWOORD

Een groot aantal mensen heeft direct of indirect meegeholpen aan de voorbereiding en totstandkoming van dit proefschrift.

De basis van het werk, dat leidde tot dit proefschrift, werd een aantal jaren geleden gelegd door verschillende instanties:
de Nederlandse Regering, door ontwikkelingsgelden beschikbaar te stellen voor dit werk,
de Landbouwhogeschool, door het werk met raad en daad bij te staan,
de Wereldvoedselorganisatie van de Verenigde Naties, door dit werk als een project ten uitvoer te brengen,
het International Institute of Tropical Agriculture, Ibadan, Nigeria, door het project en mij, als jonge, onervaren afgestudeerde binnen het kader van zijn opdrachten te accepteren.

Slechts een paar mensen wil ik hier vermelden van al degenen, die bij dit werk betrokken zijn geweest en hun bijdragen hebben geleverd:

Dr. H. Albrecht, Dr. J. Moomaw, Dr. D. Greenland, Dr. F. Moormann van het I.I.T.A., alsook Dr. G. Wilson voor de samenwerking bij het groente-project,

Dr. H. von Hülst en W. van Gilst van de Wereldvoedselorganisatie,

Prof. Ir. A. Moens en Prof. Ir. H. Kuipers van de Landbouwhogeschool te Wageningen, die het werk vanuit Nederland hebben begeleid en bereid zijn geweest als promotoren op te treden, waarvoor ik hen zeer erkentelijk ben.

Tot slot wil ik hier ook mijn ouders bedanken, die door hun hulp en stimulans het mogelijk hebben gemaakt, dat ik aan dit werk kon beginnen.

CONTENTS

1. GENERAL INTRODUCTION

This mechanization study was undertaken with three major objectives in mind. The first was to collect and analyse information on general aspects of mechanization and its effect on social and economic factors for West Africa. The second was to conduct some model studies on different systems of mechanization and to establish which operations in the production process present the biggest labour bottlenecks and are most limiting to an increased area under cropping. The third was to perform specific soil tillage and weed control studies, since both literature and model studies indicated that these operations are the most common bottlenecks in the pre-harvesting stage of the production process. These tillage and weed control studies were conducted to establish which operation or practice is most suitable under different soil and topographic conditions.

In Figure 1 three major factors are presented as constituting agriculture. Mechanization is only a part of one of these factors and is as such no answer and also no problem in itself. Its inter-relationships and interaction with other inputs and factors will determine its possibilities, applicability, problems and prospects. An attempt is made in this study to put mechanization in that light and to present its relation to, and bearing upon, farming in the tropics.

Underlying this investigation is the basic problem of how to increase food production in a hand farming system, based on subsistence farming and shifting cultivation. With the present technological (traditional) aids and farming methods, no substantial increase in food production per worker and per man-year is likely to be obtained. This state of affairs, if it continues, seems unlikely, therefore, to improve living conditions or bring about more wealth for the countries in West Africa, where up to 80 or 90% of the population is currently engaged in food production.

Mechanization in this study is regarded in its broadest sense of implying any tool or practice used to plant, produce, harvest or process an agricultural crop.

The second aspect of this study has two parts. The first is a model study on rice mechanization systems, based on available data on time and labour re-

AGRICULTURE

SOCIO-ECONOMIC RELATIONS	ENVIRONMENTAL FACTORS	TECHNOLOGICAL INPUTS
– rural development	– soils	– seeds
– labour demand/supply	– crops	– nutrients/chemicals
– marketing facilities	– climate	– irrigation/drainage
– rural migration	– rainfall distribution	– mechanization
	– topography	– tillage/weed control
		– crop maintenance/ protection
		– harvesting/threshing
		– post-harvesting

FIG. 1. General aspects of agriculture and the place of mechanization in it.

FIG. 2. The field work was carried out at this institute.

quirements for the various operations in producing rice, while the second is a field study on vegetables with two systems of mechanization.

The third aspect, which includes studies on soil tillage and weed control, has been chosen deliberately, since, as many farm surveys show (IITA, 1974), more than half the working time for producing food crops, is spent on land preparation and weeding. Furthermore, these two aspects of the crop production process could, as will be shown, have a direct bearing on the main power source desired or needed and, therefore, on what type and level of mechanization can be selected and recommended.

These soil tillage studies were undertaken at four locations along a toposequence:
two under 'upland' conditions and two under 'hydromorphic' conditions.

Apart from studying the yield potential of different tillage practices, some related physical and chemical soil parameters were also measured.

The studies were carried out at the International Institute of Tropical Agriculture, Ibadan, Nigeria, and made possible, through an 'International Coordinated Research Project on the Mechanization of Rice Production', by the Food and Agricultural Organisation of the United Nations, by the Dutch Government through the Agricultural University of Wageningen, the Netherlands, and by the International Institute of Tropical Agriculture, Ibadan, Nigeria, which also provided the opportunity and assistance to conclude the field work and the investigations.

2. PRINCIPLES OF MECHANIZATION AND MECHANIZATION STRATEGY

2.1. Introduction

A man working by hand has obvious limitations in terms of output and capacity. However, he fits in well with his traditionally grown cropping system and existing society and culture. Change will bring adaptation problems of a socio-economic or political nature, to which an individual and a society will react in making the change fit again.

In this chapter some of the factors affected by technological change will be discussed and illustrated by a general introduction of what mechanization is, can be, or can do, and which different types and levels of mechanization exist and how they can be applied.

2.2. Objectives

Parry (1971) states the general objective of mechanization as: 'to enable highly or lowly paid workers to produce maximum output with least toil, providing a high quality result by way of valuable marketable products of high value'. More specific objectives are manifold and reiterated many times (Stout, 1966: Kolawole, 1973; Abercrombie, 1972; Stout, 1971; Parry, 1971; Oyenuga, 1967; Overwater, 1974; Moens, 1974; Friedrich and van Gilst, 1971; Harris et al., 1974; McColly, 1971).

Some of them are:

1. to bring additional land under cultivation, either by clearing new areas or by utilizing land unsuitable for hand cultivation;
2. to reduce labour requirements, especially during peak periods, and to increase labour employment during slack periods;
3. to increase total employment;
4. to convert animal power feed production areas to human food production purposes;
5. to increase the output per agricultural worker, thus raising the agricultural productivity and farm income;
6. to increase the productivity of the land through improved agricultural operations, giving higher yields and by growing additional crops per year;
7. to improve the timing of the operations to make use of optimum tillage and planting dates, to avoid unsuitable weather conditions, to reduce effects of weeds, to harvest at the optimum time;
8. to facilitate the introduction of new and more intensive rotational farming systems;
9. to reduce drudgery in agricultural work and to improve the working en-

vironment, thus making farming more attractive;
10. to improve the dignity of the farmer;
11. to improve water supplies and water control systems;
12. to reduce spoilage, waste and other losses, resulting in better quality farm products;
13. to improve the distribution of commodities through better transportation facilities.

All these objectives do not necessarily have to apply for any given set of conditions; some may be dominant in one situation, whilst others may be most important in different situations.

Also priority differences will exist in objectives between an individual farmer, a farming community or a country and agricultural policy as a whole. GEMMIL and EICHER (1973) differentiate between the effects of changing technology on private or financial profitability relating to the farmer or a village, as distinct from economic profitability relating to a country as a whole. They indicate that an individual may have different objectives than his country and its policy.

2.3. ADVANTAGES, DISADVANTAGES AND LIMITATIONS

A great many advantages of mechanization are incorporated in the objectives, as pointed out in 2.2.

They can be summarized as follows:
1. increased land and labour productivity;
2. increased yields through more efficient and better timed operations;
3. higher profits;
4. reduced costs;
5. reduction of drudgery;
6. reduced losses through better post-harvesting operations.

In trying to introduce higher technological inputs, however, there are at the present stage of development in most developing countries, and especially in West Africa, many limitations and constraints, which act as major obstacles for the succesful application of these new inputs.

Five categories of such problems are identifiable, although several of these are interwoven and complementary:
1. physical and biological factors;
2. technical factors;
3. educational factors;
4. economic factors;
5. social factors.

Physical and biological factors, which can act as limitations are: water, soil, weeds, climate, the farm itself, etc.. Drainage and irrigation at the desired time are important factors for mechanization to succeed, as well as dry weather during land preparation, planting and harvesting (OVERWATER, 1972). Weed control problems, in particular grasses, can prove a severe limitation for an increased area under cropping or crop intensification, and therefore for increased technological inputs, if proper chemicals are not available on time (MOODY, 1973). The present structure of farms has tremendous limitations. The limited sizes with multiple small plots scattered around, the generally poor accessibility of the plots, and the 'slash-and-burn' technique of land clearing, make mechanization practically impossible (KOLAWOLE, 1973).

Restricting technical factors are multiple. Even if equipment is acquired, the supply and availability of spare parts, fuel and lubricants are usually in short supply or the workshops necessary to do repair works do not exist except in the cities, which may be far away. An example of these problems was given by ANON (1971b); a dealer in the Western State of Nigeria could, in 1969/1970, only repair 17 of the 304 breakdowns in agricultural machinery within 6 weeks, while 287 remained for 2–9 months in the workshop due to the lack of spare parts.

Educational factors include the shortage of qualified planning, executing and working staff to cope with the technical problems posed by introducing higher technological inputs. This shortage has been indicated by FAO (1970b) and JOHNSON et al. (1969). Also, illiterate farmers cannot really be expected to take adequate care of equipment.

Socio-economic factors may well prove to be the most important in the long run. The low yield levels, the primitive farming practices and conservatism among the farmers, the very limited financial resources at the disposal of the farmer and the general abundance of labour keep them in a vicious circle, out of which only considerable resources from outside could help them in the foreseeable future. With the present yields, mechanization is not an economic proposition, which it can only become if a farming system can be developed, maintaining soil fertility and allowing for at least double cropping. Even in that case mechanization will only be feasible if, alongside it, better varieties are available, as well as fertilizers and chemicals for pest, disease and weed control, at reasonable prices and if optimum use of land and water resources is made. Credit and credit facilities are limited and in their absence, new technological inputs cannot be acquired by the majority of the farmers. The population density and the availability of labour is a much debated issue and can offer enormous constraints for a farmer and community if new technological inputs are not applied with care. This aspect will be discussed in greater detail in paragraph 2.8. Present markets and marketing channels are inadequate and insufficient to cope with commercialized agriculture and food production and will, in the long run, be major limiting factors in firstly, getting the technology to the farmer with proper sales and after-sales services and secondly, in having the grown produce properly marketed and sold at fair off-farm prices. The inflexibility of farm structures and land-tenure arrangements also impose serious restrictions (KOLAWOLE, 1973). FLINN et al. (1974) report the absence of profitable innovations for food crops and unfavourable price relationships, at least until recently, as limitations.

Up to now, most Government policies in developing countries related to agricultural mechanization and mechanization programmes have been unstable and were prohibiting rather than stimulating the applications of improved and desirable technological inputs (FAO, 1973c).

Included in the restrictions, are possible disadvantages of mechanization:

1. the capital used for mechanization could have been better used for other purposes (FRANKE, 1974);
2. the labour released cannot be employed elsewhere, thus also increasing the urban drift (STOUT and DOWNING, 1974);
3. production or production structures become adversely affected, e.g. increase in farm size is stimulated and this will benefit the large farmers more than the small farmers, thus increasing social differences (FRANKE, 1974; LUNING, 1974);
4. if equipment is imported, it may mean a serious drain on the foreign exchange, especially with the rising prices of materials and fuel;
5. mechanization, if not applied wisely and well balanced, can have a disturbing effect on the farm, resulting in either unexpected labour deficits or labour surplus during certain operations or periods of the year;
6. mechanization, if not applied alongside other necessary inputs, such as suitable soil, irrigation, high yielding crops or suitable rotations and fertilizers, may prove to be uneconomic or a failure, especially if the necessary technical and managerial support is inadequate. Moreover, mechanization has to be adapted to prevailing soil conditions, otherwise soil deterioration and erosion may result, and the right crops have to be grown under the prevailing agroecology to make mechanization profitable.

2.4. INTRODUCTION OF NEW TECHNOLOGY

As GARRARD (1971) states: 'one of the greatest problems of a sociological nature, particularly in Africa, is trying to discover the reasons for small farmers not accepting new tools, new ideas and improved methods and techniques of agriculture'. NORMAN (1973) reasons that new technology, in order to stand a reasonable chance of being adopted, has to be technologically viable, economically feasible and adaptable to the indigenous situation.

Several proposals have been made on how to introduce new technology and through what stages these developments have to go before a subsistence and shifting agriculture will become commercialized. RUTHENBERG (1971) argues that changes in adopted systems may either arise within the farm or outside it, and may be caused by new technical possibilities (new seed, pest control, irrigation, etc.) or be the result of a wide and complex range of social and economic factors, such as population density, technical progress, development of urban purchasing power and export markets or changes in human aspirations. LUNING (1974) lists some, mostly inter-related factors, which can bring farmers to adopt innovations: the profit of the innovation compared to the old situation must be in the order of 2 to 3 times as high during the initial phase of the adoption; the risk and uncertainty should be avoidable or minimal; the prices of production factors and product play either a stimulating or retarding role in the adoption process; the speed and effectiveness of extension on possible new innovations. He concludes, that an accumulation of these factors usually results in the fact that bigger farmers profit first from new possibilities. FRANKE (1974) indicates, that from the farmers' point of view mechanization can be attractive, if (a) cost of hired labour is high, (b) labour, especially in peak periods, is scarce, (c) the cost of animal power is high, (d) expansion of area becomes possible, (e) the intensity of cropping can increase, (f) the period of land preparation is limited by soil and climate, (g) the released family labour can be made useful outside their own farm, (h) losses are reduced, (i) drudgery is lessened. He states, that in densely populated developing countries with small farms factors (c) and (e), and in less densely populated countries factors (b), (c), (d) and (e), and that locally factor (f) can be so important that mechanization becomes attractive or desirable. ABERCROMBIE (1972) indicates that, when the labour force at last starts to decline, all the increase in demand for agricultural products will have to be met by raising the productivity of labour at a rapidly accelerating rate, which will stimulate mechanization. He states: 'The degree of tractorization appears to be quite closely related to the level of income per head and the extent to which the population is urbanized, indicating the likely importance of higher wage rates in stimulating mechanization'. FLINN et al. (1974) mention that the ability of the small farmer to adopt new technology appears to be inversely related to the severity of land pressure in upland areas, i.e. farmers in the most critical nutritional and financial position are least able to implement technical change. DE BOER (1974) differentiates two stages in the development of agriculture. In the first stage, better varieties, fertilization and plant protection are important. This should be accompanied by a thoroughly planned strategy to ensure national food production, a programme for extension, training and educational services, and a system for storage, processing and marketing. In the second stage, mechanization, water management and farm size become important. This stage should be accompanied by a national strategy for agricultural education, legislation of land and water use, and extended infrastructural improvement.

LUNING (1969) uses in his study the following three terms to indicate development: traditional agriculture, transitional agriculture and commercial agriculture, and mentions management as being important in commercial agriculture, while it is hardly of importance in traditional and transitional agriculture. He indicates, that, for Surinam conditions, the most important technical factor responsible for the sharp contrast between traditional and transitional agriculture is water control during paddy cultivation, which is essential but beyond the control of the individual farmer and which is the limiting factor before any other new agricultural input can be introduced. This point is also stressed by POTHECARY (1970) and RUTHENBERG (1971).

SMERDON (1971) suggests three stages through which mechanization in the developing countries can be progressively visualized.

Stage 1: Start of agricultural mechanization. This may last 5–10 years depending on the emphasis placed on agricultural mechanization by the National Government.

Stage 2: Progress in mechanization. This may last 10–20 years or longer depending on local problems and the interest and support of the Government.

Stage 3: Towards total mechanization. In this stage the path to be followed in the development of mechanization is well defined and the needs of the country have been determined. The education, research and necessary service organizational structures have been defined and should be in operation. The sales and service networks will be developing.

JURION and HENRY (1969) differentiate four phases in the development from traditional to intensified agriculture.

Phase 1: Gradual improvement in productivity of the peasant's manual labour, with a view to increasing yields per acre. In this stage commercial investment is required to cover salaries of training, planning and research staff.

Phase 2: Increased yields per acre achieved by continuation of the methods used in the first phase. Communal investment costs take the same form but with the addition of the purchase of simple machinery.

Phase 3: The best farmers increase their acreage while maintaining yields per hectare at the highest possible level. Communal investment will be the same as in phases 1 and 2, but on a larger scale.

Phase 4: The most active and skilful peasants increase the size of their farms and work them with the aid of equipment acquired through their own savings. In this phase communal investments grow smaller as private investments increase.

Most of these proposals do indicate that mechanization cannot be seen and treated as an isolated factor in the development process from traditional to commercialized agriculture. They also make it clear, that mechanization does not have primary importance in this process, but in general can only be applied successfully after other conditions are met or set in motion.

The socio-economic problems related to the introduction of new technology may prove to be of major importance in many instances, especially for Africa, south of the Sahara (FAO, 1970b), as will be discussed and repeated in the following paragraphs.

2.5. LEVELS OF MECHANIZATION

2.5.1. *Introduction*

Mechanization has progressed into different directions and intensities in different agro-ecological and/or socio-economic conditions. BARKER et al. (1973) argue that in time economic profitability should dictate the level of mechanization, and indicate that profitability is influenced by the technologies available to the farmer at any given time and at the factor and product prices he faces.

GILES (1974) quotes the following figures for the distribution of agricultural power and illustrates that there are big differences in farm power for the different continents.

	total kW(HP) per ha	% of available power/ha		
		human	animal	mechanical
Asia (excl. Red China)	0.16 (.22)	26	51	23
Africa	0.075(.10)	35	7	58
Latin America	0.19 (.25)	9	20	71
Japan	2.23 (3.0)	7	3	90
U.S.A.	1.0 (1.4)			100 (approx.)
Netherlands	3.5 (4.7)			100 (approx.)

In the following paragraphs the main differences between the various sources of farm power will be discussed separately, although usually more than one type of power exists in a given situation. The application of different power sources is probably least developed in West African agriculture, where manual labour is still the main power input. This can be said especially of the humid parts of West Africa, where animal power cannot be applied, while the numbers of tractors in use in West African agriculture are still very small, as indicated in Table 1.

TABLE 1. Number of two-wheel tractors (A) and four-wheel and crawler tractors (B) in use in some West African countries (from FAO, 1973b).

Country	61–65		69		70		71	
	A	B	A	B	A	B	A	B
Dahomey	7	65	9	76	10	78	10	80
Ghana	548	1732	600	2550	650	2700	650	2800
Ivory Coast	8	399	50	1231	50	1412	50	1619
Nigeria	51	614	85	900	90	950	95	1000
Senegal		200		460		490		540
Sierra Leone	5	99	12	220	12	230	15	250
Togo	5	37	10	57	12	60	14	62

2.5.2. *Manual labour*

At present manual farming is still associated with shifting cultivation and subsistence farming in West Africa.

As regards the prospects for improved hand-based systems and tools many different opinions and suggestions have been put forward. PAPADAKIS (1966) states that 'the greatest disadvantage of shifting cultivation is that all tillage operations are done by hand. Under such conditions the area grown per capita is small; the farmer faces the dilemma of either sowing a very small area and tending it well, or sowing a greater area and then being unable to control the weeds. Whatever his choice may be, production is low'. FLINN et al. (1974) argue that a strategy based on more intensive use of labour is not likely to find a high rate of acceptance in West Africa. THIERSTEIN (1973) considers it essential for hoe farmers to have some additional power for an improved cultivation system to develop. KHAN and DUFF (1973) are highly doubtful that labour productivity can be increased substantially through greater use of manual power. HOPFEN (1969) considers improvements of hand-powered farm implements of great importance as it is one of the first steps that can be taken to raise crop yields and the farm income. ANON (1971b) and RANA (1971) suggest that limited improvements on hand-tools could be made but that many technical and social problems will have to be overcome to make these improvements and have them accepted by the farmers. A man has limited power (see par. 2.7.3.2), but his power is versatile and directly and easily applicable. The area he can work is necessarily limited, and some estimations and suggestions have been made as to the area of land a manual farmer can handle adequately. RENAUT (1974) quotes 1 ha per adult worker as reasonable for manual cultivation. KLINE et al. (1969) quote figures from Tanzania, indicating that the manual farmer could till, plant and care for 1.2 ha of cash crops in addition to 1.2 ha of food crops. MUCKLE et al. (1973) mention 3 ha as a reasonable average for a farming family. From farm surveys in Western Nigeria, FLINN (IITA, 1974) reports the modal cultivated area to be 1 hectare per farm, with mean farm sizes of about 1.65 ha. He reports that one man can cultivate no more than 1.4 ha, both in the forest and the derived savannah zones. From the more densely populated parts of Eastern Nigeria he reports the modal areas to be between 0.2 and 0.8 ha. OLUWASANMI (1966) indicates that one important feature of the agricultural work in a traditional farming society can be the division of labour on a basis of sex. From a survey in Eastern Nigeria he reports men to work 5.28 hours per day, out of which 3.35 hours is spent on farm work, and women to work 6.41 hours per day, of which 2.41 hours is on farm work.

The hand-tools a farmer in West Africa at present has at his disposal are mainly a hoe, a cutlass, an axe and perhaps a sickle or knife for harvesting rice; also a bicycle could in many instances be regarded as part of his equipment.

To improve these implements, which are the result of many years use and adaptation, would surely be a difficult task with a limited chance of success.

However, there is a range of hand-operated equipment available, as yet unknown to the African farmer, which, without major design or adaptation changes, could possibly be employed successfully in traditional African farming. These include seeders, sprayers, threshers, winnowers, etc. which can also be made locally and could be applied in the present system without affecting major socio-economic difficulties. BURRILL (1973) calls for this type of small hand-operated equipment for multiple cropping systems.

As indicated by FAO (1970b) and FLINN et al. (1974) human power will continue to be a main source of energy for farming in Africa, until such time as

FIG. 3. Manual land preparation with a short-handled hoe.

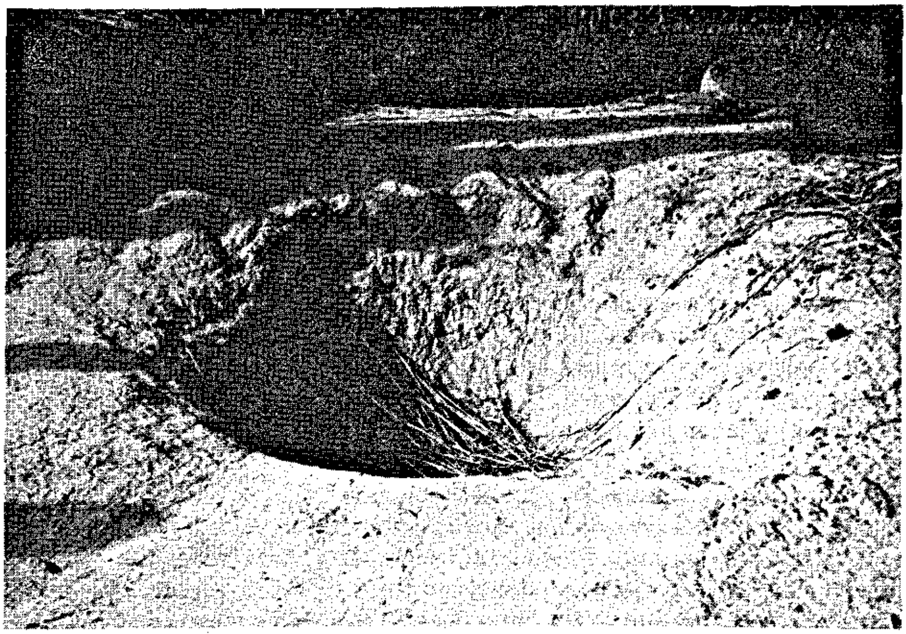


FIG. 4. Threshing pit for manual rice threshing.

economically feasible systems of mechanization are developed for small farmers.

2.5.3. *Animal draught*

The animals which can be used for traction belong to the following species: bovines, equines, asinines, camels and mules. For farming work, however, bovines (especially oxen) are mostly used in Africa.

It is argued that oxen have advantages over other species (FAO, 1972c) by virtue of the fact that they work slowly but unflaggingly, that they are hardy and strong and easy to feed, that their harnassing is simple. Furthermore their purchase price is on the whole attractive and at the end of their working life, they may be sold for meat. Some of the disadvantages recorded are, that they are not considered a friendly animal by many African farmers and that they need relatively large grazing areas. In addition, they are considered more difficult to train and handle than horses and their working rate is slow (FAO, 1972a).

As a general indication, the power oxen can exert for continuous working is about one tenth of their weight (HOPFEN, 1969; FAO, 1972c).

Animal draught offers a number of advantages over alternative power systems (JURION and HENRY, 1969; KLINE et al., 1969; KOLAWOLE, 1973):

1. It is less costly than mechanical traction, both in terms of price and running costs (easy management) and therefore within the reach of many farmers;
2. It has a multi-purpose function: farm power, meat and manure. FAO (1972c) reports that an ox stabled at night is able to produce 3.2 tons of manure a year;
3. Replacements are home bred, thus minimizing foreign exchange requirements;
4. The profit from keeping livestock rises;
5. Oxen can be used satisfactorily on small and scattered fields, even if they are not well cleared.

As disadvantages of animal draught, the following are mentioned (JURION and HENRY, 1969):

1. It cannot work heavy soils and is only usable on soils that are naturally light or have been loosened by other means and have been completely cleared;
2. The quality of work done is often imperfect;
3. The capacity is limited in output per hour and hours per day. Most animals can only work effectively for 4–5 hours a day (FAO, 1972c);
4. At the end of the dry season, when they are most needed for land preparation, they are often in a poor condition (MUCKLE et al., 1973).

There are also a number of factors which limit the opportunities to employ animals in agricultural work. They are related to factors such as whether or not a livestock tradition exists, whether sufficient grazing land is available, whether adequate land clearing has been done, and whether there are no serious threats to the health of the animal. The latter factor, through the presence of *Trypanosomiasis*, carried by the tse-tse fly, has greatly reduced and restricted the scope

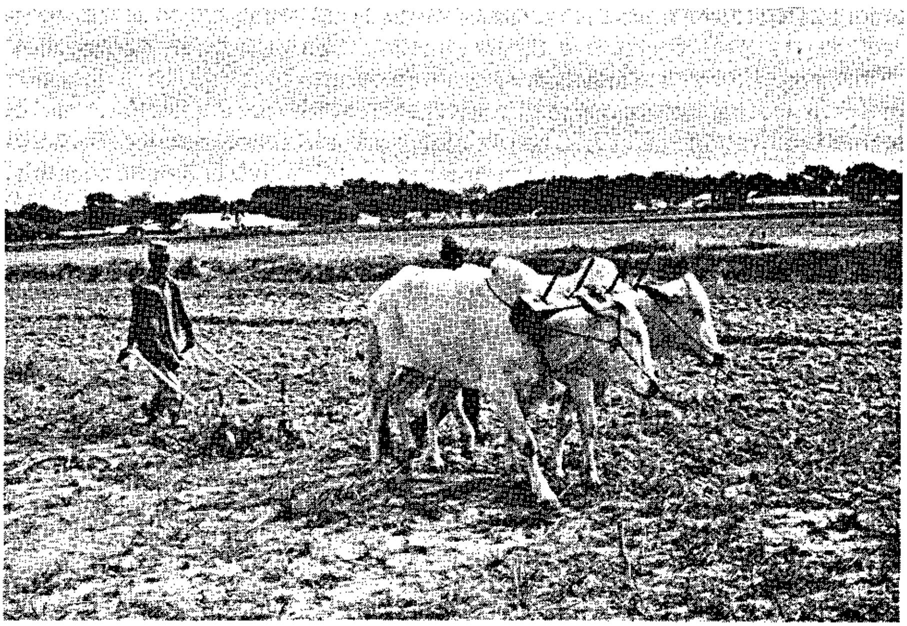


FIG. 5. Animal traction is not applicable in the humid parts of West Africa.

for keeping and using animals in the humid parts of West Africa. This situation is unique for West Africa.

As summarized by FAO (1971a) feelings about the applicability of animal draught differ greatly.

KHAN and DUFF (1973) and KHAN (1975) argue that it is highly doubtful whether productivity could be increased substantially in the tropical Asian region through greater use of animal power and suggest that improved animal-drawn implements can only be of marginal benefit in the developing countries. OREV (1972) argues that animal draught is stranger to Africans than mechanized farming, while it does not have the prestige appeal of the tractor and he feels that the time and money spent on efforts to introduce animal power could be much better invested in the search for newer ideas. RANA (1971) and ANON (1971b) indicate that draught animals have only a very limited role to play in the development of agriculture in the areas free from the tse-tse fly. KLINE et al. (1969) and GILES (1974), on the other hand, indicate that animal draught will remain a major source of power for some time to come for West Africa and Asia respectively. VAN GILST (1975) claims that animal power will remain a most important aspect in agriculture in many countries for years yet and that research into improved bullock implements should have a high priority. BOSHOFF (1972) suggests the ideal power supplement for farmers, who are in the transitional stage between subsistence cultivation and commercial farming, to be draught animals, if they are available.

There are several reports on how well animal draught compares with manual labour as well as on the area that can be worked with oxen.

RENAUT (1974) reports that the use of animal traction helps to increase agricultural returns by 80% and daily agricultural returns by 25%. The major cause of this increase is the expansion of cultivated area: 1 ha per adult worker unit in manual cultivation versus 1.90 ha per adult worker in animal traction. RAMOND (1966) also reports that animal traction can increase family income considerably, not through an increased revenue per ha but through an increased area under cropping; under the most favourable conditions a factor of 1.7 to 1.8 is suggested. KLINE et al. (1969) report that it is estimated for Ghana that, to justify owning oxen for farm power, a farmer should have 4–6 ha of crop land, 70 days of tillage work and 120 days of cart work per year for each pair of oxen. THIERSTEIN (1973) indicates that, in comparing different levels of mechanization, the cost advantage is undoubtedly swinging more in favour of ox cultivation.

MONNIER (1971) compared different intensities of animal traction and reported the following figures:

	area under cropping (ha)	number of active workers needed	area per active worker (ha)	net income /ha
1. light animal traction (horse and donkey traction with light equipment)	5.2	3.4	1.53	100%
2. animal traction, semi-intensive (oxen with recommended equipment)	8.4	5.1	1.65	182%
3. animal traction, intensive (oxen with high capacity equipment)	12.0	6.3	1.90	255%

He concludes that the most intensive application of animal traction is most economical, despite its higher costs.

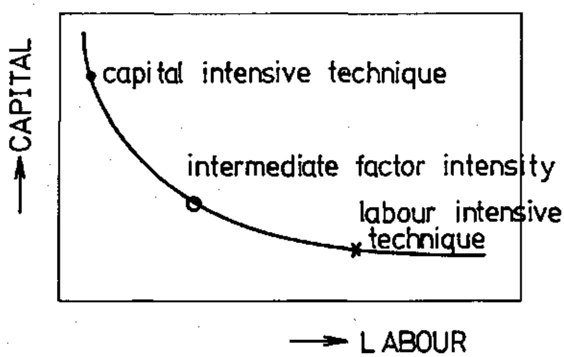
HOPFEN (1969) lists some qualities for improved hand-operated and animal-drawn tools and implements. They should be adapted to allow efficient and speedy work with the minimum of fatigue; not harmhul to man or animal; of simple design, so that they can be made locally; light in weight for easy transportation; ready for immediate use without loss of time for preparatory adjustments; made of easily available materials. As far as animal traction is concerned he states that 'the timely performance of light work during seasons of short duration or during a rapid succession of work for multiple cropping, often requires only a small engine as (additional) power source, but this must be at the ready disposal of, and hence owned by the individual farmer'.

KLINE et al. (1969) indicate that the major limitation for the animal farmer is weeding, much as primary tillage is for the manual farmer. POTHECARY (1970) and HOPFEN (1969) argue that improvements in labour utilization and developments in animal equipment will continue alongside increased use of more developed forms of mechanization. The capital investments for animal draught, however, are relatively small but they lead to a strengthening of the farm economy and fuller employment of the rural labour force and the creation of that capital which is so necessary for larger investments, eventually in mechanically powered mechanization (HOPFEN, 1969).

2.5.4. *Mechanical power*

2.5.4.1. Introduction

As a general expression of the relation between capital and labour DUFF and ORCINO (1971) presented the following picture:



The labour intensive techniques based on hand and animal power were discussed in the previous two chapters.

In the following chapters, techniques with increased capital inputs will be described. Only two main exponents will be differentiated: systems based on small two-wheel tractors (small-scale mechanization) and systems based on four-wheel tractors (large-scale or conventional mechanization). This is based on the two present distinct agricultural mechanization technologies. The first, exemplified by the Japanese approach, involves small, low-powered equipment mainly for irrigated rice, with major emphasis on small holdings, high labour costs and high labour inputs. The second could be referred to as the Western approach, where large, high-powered equipment is used for dryland farming mainly and with major emphasis on relatively larger holdings and aimed at the saving of labour.

2.5.4.2. Justification

Although higher technological inputs may result in a variety of socioeconomic and technical problems, it is likely that its realization and application will become increasingly faster and more important.

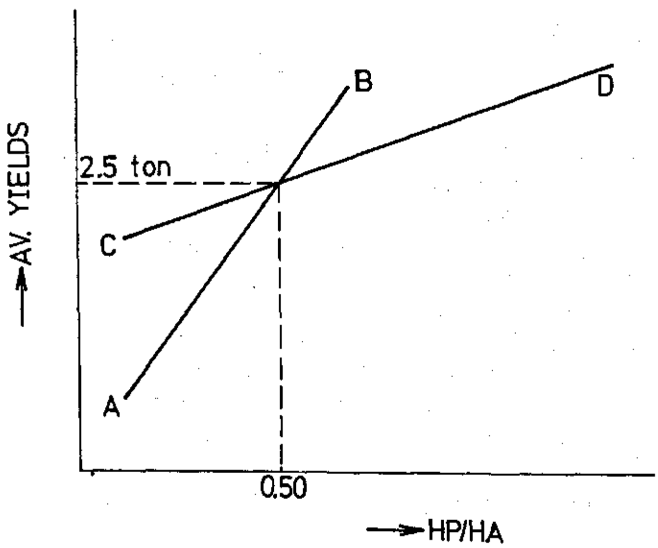
FAO (1970) provided some figures for Africa, south of the Sahara, as to what proportion of the rural population has to support the non-rural population. In

1962, 82 members of the rural population were supporting 18 non-rural members as well as themselves. This will have changed by 1985 to 70 and 30 respectively. This means that farmers would have to double the volume of marketable output for local consumption merely to maintain existing urban consumption. This, with the present technology based on manual labour, is not possible and power mechanization will be needed.

The question, therefore, is not whether to mechanize, but how, when and to what extent (MOENS, 1974; KOLAWOLE, 1973; FAO, 1971a; KHAN and DUFF, 1973).

Different reasons for the justification of higher technological input and mechanization have been suggested. REESER (1975) argues that in tropical South America and Africa, where enormous land and water resources await development, labour intensive projects stand only limited possibilities of success. The relative vastness of the areas together with rapid tropical re-growth and time factors require mechanized development. When jungle terrain is mechanically cleared, intensive mechanized cropping can make these new areas produce faster and improve the chances for future productivity.

GILES (1973) drew up a chart relating the H.P. input per ha and the average yields for many countries and presented the following graph:



He explains that in a nation's agricultural development, farmers tend to follow along the line A-B. That is, they increase yields faster than mechanical power. But when the grain yields are up to around 2.5 tons per ha they tend to increase power at a greater rate than yields, line C-D. While farmers get in the first instance greater gains from money invested in such inputs as fertilizers, irrigation, pesticides and improved varieties, they later invest in machines for a continued and more modest gain in yields, reduced costs and drudgery, and for convenience. The figure suggests that at around 2.5 tons per ha machines generally, but depending on local conditions and price relationships, compete successfully with other major inputs, and that at that stage a power input of at least 0.5 HP (0.37 kW) per ha will be desirable.

FAO (1970b) also mentions this figure of 0.5 HP (0.37 kW) per ha as being the minimum required to achieve the full potential for high yields and MOENS (1975) deducts from FAO figures that an increase in the level of energy corresponds with higher yield levels.

There is, therefore, little doubt that properly utilized and managed mechanization will become a necessity (MOENS, 1975), combined with such inputs as fertilizers and herbicides (PARRY, 1971; PAPADAKIS, 1966). Tractor power would also seem likely to ultimately replace manual and animal power (WADHWA, 1969; KHAN and DUFF, 1973; DOWNING, 1972). FAO (1970b) reasons that power mechanization will become a necessity, since the contribution of additional human labour or draught animal power to bridge the gap between present availability of power and future requirements is relatively small.

KHAN (1971) argues that to keep the land in near-continuous production, mechanized production methods are of urgent necessity to the tropical farmer, especially since the income of farmers who have adopted new, high yielding varieties and cultural practices have usually risen sharply and this has provided an impetus for mechanized cultivation.

ABERCROMBIE (1972) also mentions that the degree of tractorization appears to be quite closely related to the level of income per head and the extent to which the population is urbanized, indicating the likely importance of higher wage rates in stimulating mechanization.

Whether tractor mechanization can be justified through higher yields is doubted by several authors (KLINE et al., 1969; ABERCROMBIE, 1972). They argue that improvements in such inputs as seeds, herbicides, irrigation, etc. have a far greater impact on yields, even though some mechanization can sometimes be an essential part of the overall technological package. Other reports, however, indicate that mechanization, especially through more efficient or better timed tillage and weed control operations, can substantially increase yields (THIERSTEIN, 1973; CHARREAU and NICOU, 1971). It should, however, be pointed out that the effect of mechanization is very dependent on the environment, including the past history of the site.

2.5.4.3. Small-scale mechanization

This type of mechanization is based on two-wheel tractors, sometimes called: single-axle tractors, walking tractors, garden tillers or rotary tillers. Also small four-wheel tractors can be included in this category, since they are usually not a scaled-down version of the standard four-wheel tractors, but rather of special design.

Several classifications of small tractors have been made (CURFS, 1974b), based on:

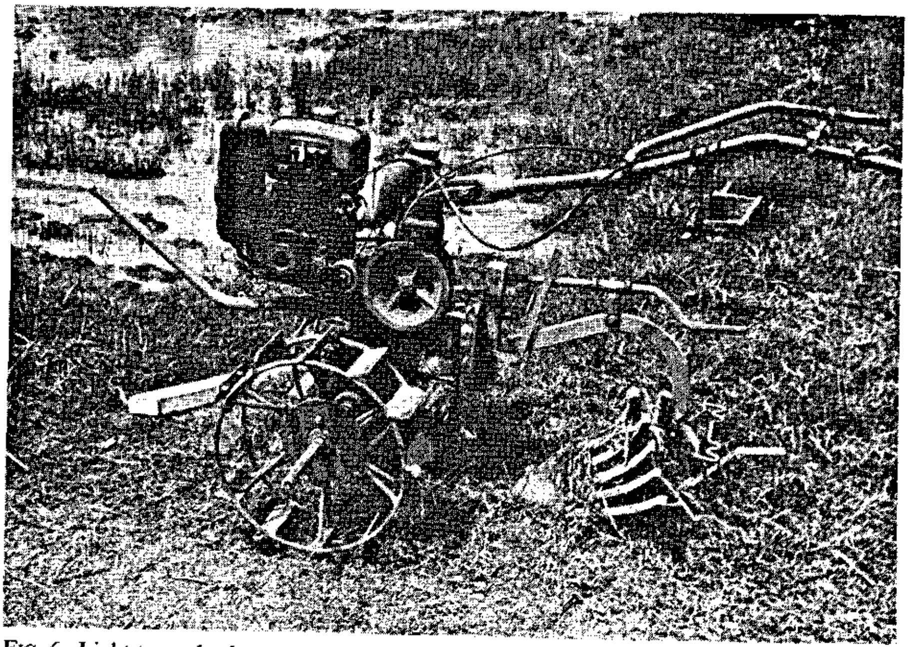


FIG. 6. Light two-wheel tractor (4.4.kW).

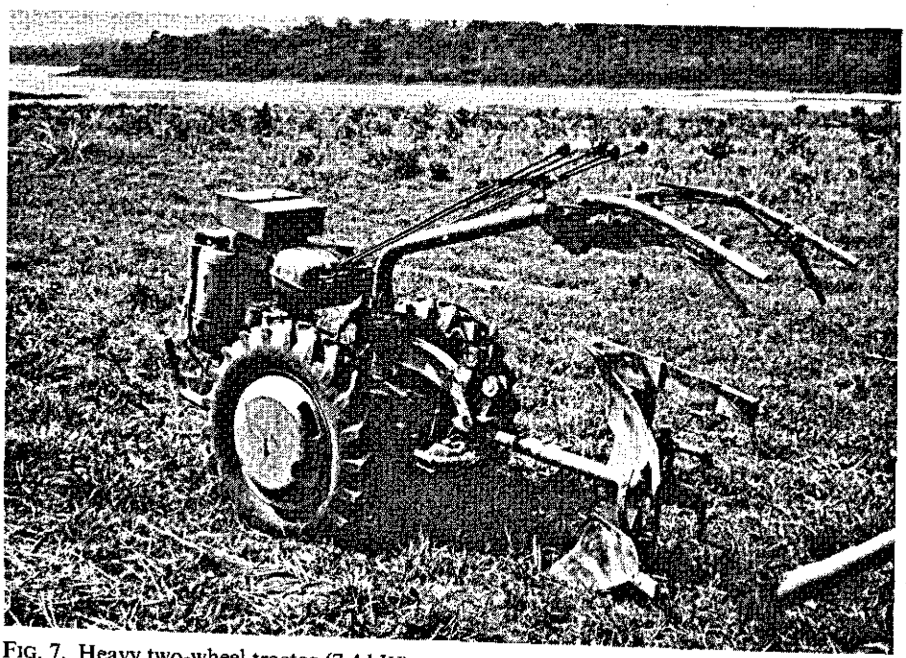


FIG. 7. Heavy two-wheel tractor (7.4 kW).

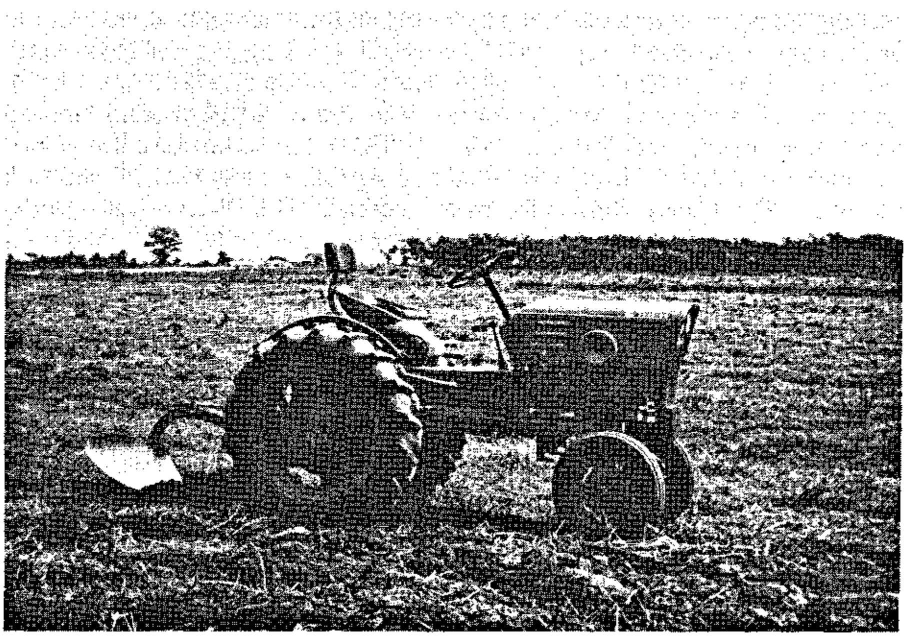


FIG. 8. Small four-wheel tractor (10.4 kW).

(a) one-axle/two-axle type;
(b) horsepower and gearing system:
  1. light two-wheel types, 2.5–6 HP, without gearbox, usually without PTO;
  2. medium two-wheel types, 5–10 HP, with gearbox, usually with PTO;
  3. heavy two-wheel types, 10–15 HP, with gearbox and PTO;
  4. light four-wheel types, 10–25 HP, with gearbox and PTO;
(c) steering system:
  1. no steering clutches (in general the tractors under b.1);
  2. steering clutches (in general tractors under b.2 and b.3);
  3. differential and brakes (in general the tractors under b.3 and b.4);
(d) type of engine and fuel:
  1. 2-stroke engine, petrol/oil mixture;
  2. 4-stroke engine, petrol/kerosine;
  3. 4-stroke engine, petrol;
  4. 4-stroke engine, diesel.

The applicability of two-wheel tractors in the developing countries has been a major issue of critical discussions over the years. Advocates of this type of mechanical power have argued, that it can be cheap, relatively simple and within the reach of individual small farmers (KHAN and DUFF, 1973; WIJEWARDENE, 1975; OYENUGA, 1967; KELLOGG, 1975; RUTHENBERG, 1971). Others, however, have been stating that mechanization based on two-wheel tractors could be usefully applied only as a transition between hand and full-scale mechanization or for some specialized crops such as vegetables or irrigated rice (DOWNING, 1972; WADHWA, 1969; POTHECARY, 1970; ABERCROMBIE, 1972; FAO, 1970b). Others argue that potentially two-wheel tractors could be usefully applied under some conditions (MOORMANN et al., 1974), but so far have not gained acceptance in West Africa (FLINN et al., 1974; THIERSTEIN, 1973). Some look very critically at the prospects for two-wheel tractors in West Africa (KOLAWOLE, 1973; GARRARD, 1971), especially for use under dry-land conditions (MUCKLE et al., 1973). KOLAWOLE (1973) states some reasons for the lack of progress in the adoption of cheap and small tractors in West Africa. Among them are that small tractors are relatively expensive, that they are not always able to carry out primary cultivations in the tropics and that the rate of work is slow and may delay planting beyond the optimum date in double-cropped areas. Furthermore, he states: 'since the small tractors are designed with the intention of appealing to individuals in comparatively high income brackets, it is by no means certain that such tractors could be produced, marketed and serviced in a way that would suit our small farmers.'

The possibilities of a simple small four-wheel tractor instead of the two-wheel type has found considerable support (CURFS, 1974b; POTHECARY, 1969; BOSHOFF, 1972). This type of tractor would not necessarily have to be much more expensive or more complex. It could offer ergonomic advantages, which the emerging African farmer is likely to favour; it has a capacity of 2 to 3 times more than that of a two-wheel tractor and can be applied successfully both under wet and dry soil conditions, in contrast to many two-wheel tractors, which are either designed for wet or for dry conditions. Enough clearance will, therefore, have to be one feature of this type of tractor to permit working under paddy conditions and to allow for inter-row cultivation as well.

Several reasons have been cited for the two-wheel tractor's great success in Japan and Taiwan, compared to its relative lack of success in other countries (POTHECARY, 1969; KOLAWOLE, 1973; TSUCHIYA, 1972; KHAN, 1972): the relatively temperate climate with soils and crops suited to low HP units; the predominance of rice as the major crop; the predominance of small holdings, which are highly productive per hectare per year; the development of the countryside with good farm access and transportation provisions; the parallel running of agricultural mechanization to industrial development, which gave rise to a high urban population and provided markets for rural producers; the high level of education; the productivity, which was already a feature of agriculture before the introduction of small tractors, so that the Japanese farmer was comparatively credit worthy, and lastly the officially subsidized prices combined with the fact that many Japanese farmers are part-time farmers. There is, however, also in Japan a trend towards small four-wheel tractors to replace the two-wheel types (MUKUMOTO, 1969).

FAO (1970b) supposes that, in most cases where two-wheel tractors are introduced they are, within 10–20 years, very largely superseded by four-wheel tractors.

One important difference between Asia and Africa should be mentioned here as regards two-wheel tractors. The acceptance socially of this type of power can be expected to come more readily in Asia where it is more a replacement and complement of animal power than something completely new. This is in contrast to the humid part of West Africa particularly, where people do not know animal draught and where this type of power unit is as new as conventional four-wheel tractors, with the main difference that the ergonomical disadvantages of two-wheel tractors may well prove to be a serious limitation for acceptance.

At present only very limited numbers of two-wheel tractors are in use in West African countries (Table 1), contrary to several countries in Asia, where considerably larger numbers of two-wheel tractors are employed (FAO, 1973b).

Several authors have reported or made suggestions on how large an area should be for a small tractor to become feasible. FRIEDRICH and VAN GILST (1971) indicate that a small tractor can be economically feasible on about 20 ha. DUFF and ORCINO (1971) report that a small tractor is more economical than animal draught above 4.2 ha and WADHWA (1969) reports two-wheel tractors to be the same cost as bullock power, but more expensive than manual power below 1.4 ha and less expensive than four-wheel tractors below 16 ha. ANON (1965) suggests that a power tiller would be economical in areas where an HP-hour costs less than 2 manhours of farm labour. FAO (1970b) reports 2 to 4 hectares under intensive irrigated conditions to be a reasonable farm size to justify the capital investment of a two-wheel tractor.

2.5.4.4. Large-scale mechanization

This type of mechanization is based on standard four-wheel tractors, as used by farmers in the United States and Europe. This technology is based on relatively large farms, high labour costs and relatively low labour availability. Its advantages are obvious: high capacity, allowing for speedy and well-timed operations and lower costs per HP than small tractors. Its disadvantages can be numerous, however, in societies with small farms, low capital availability, low labour costs and high labour availability in terms of socio-economic and technical conditions. Also erosion problems become more acute for large cultivated areas. The literature indicates that the area needed, before application of four-wheel tractors becomes possible and economical, varies, depending on country, price and crops. FRIEDRICH and VAN GILST (1971) report 50 ha and ABERCROMBIE (1972) 40–50 ha. DUFF and ORCINO (1971) report that a large tractor becomes more economical than animal draught above 67.5 ha and than a two-wheel tractor above 38.1 ha. FAO (1970b) indicates that 15–25 hectare farms are large enough to justify the capital investment of a 40 HP four-wheel tractor under intensive irrigated conditions, while 40–100 hectares will be needed for the larger wheel-type tractors in rainfed areas.

OVERWATER (1974) indicates that mechanized rice farming will be economically justified only if two crops a year can be grown, while the field size should be 0.4–1 ha for a four-wheel tractor, 2–7 ha if a combine is also used and 9–14

TABLE 2. Proposed tractor parks (×1000) (FAO, 1970b).

	Tractor park (no. of tractors)				
	Estimated	Proposed		Growth rate	
	1965	1975	1985	1965–75	1975–85
Latin America	376	570	810	4.3%	3.6%
Near East	35	71	117	7.3%	5.1%
N.W. Africa	36	49	65	3.1%	2.9%
Asia: 2-wheel	19	109	700	19.1%	20.0%
4-wheel	85	280	970	12.5%	13.2%
Africa, south of the Sahara	22	35	56	4.8%	4.8%

ha if a crawler tractor and combine are employed. Despite the mixed success so far of standard four-wheel tractors, however, many authors do agree that this type of mechanization will eventually make the greatest impact in West Africa (CERVINKA, 1971; DOWNING, 1972; ANON, 1971b; REESER, 1975; SMERDON, 1971; KOLAWOLE, 1973). Also, as indicated by ALLAN (1975), large-scale mechanization will be necessary for land clearing and development.

FAO (1970b) has made projections of the number of tractors in the developing areas of the various continents, as shown in Table 2. In these projections the growth rates of tractors will be around 4.8% for West Africa, south of the Sahara, and the number of tractors will remain comparatively modest.

2.5.5. *Discussion*

While hand-farming is cheap, it does have serious limitations for increased area under cropping, for increasing cropping intensities and for keeping young people in farming. Improvements on the existing traditional tools are unlikely to be of great importance, but introduction of new hand-operated equipment such as for sowing, spraying, etc. could possibly be done without many socio-economic and technical difficulties. The Chinese missions have demonstrated this with rice in several places in West-Africa, while the use of, for instance, knap-sack sprayers in Western Nigeria for spraying cocoa is another example.

Animal draught carries potential advantages, in that it is locally available, relatively cheap and can increase the area under cropping. It can offer some sociological constraints in that animals traditionally have been herded by nomadic tribes in West Africa, and that hoe-farmers, who have never handled animals, may have problems in accepting them. The humid parts of West Africa are furthermore unfortunate in that animal power cannot be applied because of diseases, thus ruling out animal draught for many years to come, if not forever. Two-wheel tractors have received a lot of discussion as to their applicability, but so far have not been able to find application in West Africa. More attention should be given to small four-wheel tractors to eliminate at least the ergonomical constraint, posed by present available two-wheel tractors.

Mechanical power, in so far as applied in Africa, has come almost exclusively from standard four-wheel tractors. Their impact has been stimulating in some instances although their effect has also been negative in other cases, because of inadequate planning, management and technical support and because many other necessary conditions were not met.

2.6. Mechanization policies

2.6.1. *Introduction*

Having defined the general mechanization aspects and possibilities, one can consider the actual decision making and planning on what type and what level of mechanization would possibly be most suitable and most appropriate in a given situation.

On this issue there are a number of different schools of thought, some complementing each other, while others are contradictory on certain aspects.

In the following chapters four such different 'philosophies' will be discussed, as put forward in literature, namely, intermediate technology, selective mechanization, tractor hiring services, large-scale farming versus intensification.

2.6.2. *Intermediate technology*

This term is often used synonymously with appropriate technology.

Schumacher (1975) has defined appropriate technology as 'the know-how and equipment designed to help the poor to help themselves'. Garg (1974) described appropriate technology as 'a technology which can carry out production on the smallest possible scale and yet can produce the same quality product at a competitive price compared with that of large-scale industry'. He continues that 'appropriate technology can be put into practice only when the quantum of production of industrial units is scaled down so that a larger number of people may own them and the units be dispersed widely on a regional basis'. Charles (1974/1975) indicates that the term intermediate technology is often used to describe a technology which lies midway between the primitive ones now employed in developing nations and the capital-intensive technologies prevalent in rich countries. Intermediate technology has been defined by Moens (1974) as being: low cost, low powered, simple and sturdy; by Bailey et al. (1973) as being associated with simple low income products, more capital saving, more labour (particularly unskilled) intensive, making greater use of local resources of material and labour, as compared with advanced technology; and by Anon (1971a) as the introduction of the right combination of new ideas and technical innovations at the right time and in the appropriate order consistent with the actual seasonal needs of a given rural community.

In general, it does not seem justified to use the terms intermediate and appropriate technology synonymously. Appropriate technology appears to be more of an equilibrium between a given situation and a prevailing socio-economic and technological level, while intermediate technology would seem to be one option and 'philosophy' to reach this equilibrium.

KHAN and DUFF (1973) and KHAN (1975) contend that the compatibility of a machine with its socio-economic, agro-ecological and industrial environment is just as significant, if not more so, than its function and recommend intermediate technology as the solution. The same is recommended by WIJEWARDENE (1975), arguing that machines need to involve totally the farmers and to resolve his problems; not to displace him or his way of life.

Closely related to the recommendations on intermediate technology is the contention that this type of technology could be produced locally with locally available skills and materials (MOENS, 1974; MOENS, 1975; KHAN, 1971; KHAN, 1972; PILLAINAYAGAN, 1974; WIJEWARDENE, 1975) and that with the advancement of agricultural mechanization the concurrent growth and development of the indigenous farm equipment industry is absolutely essential (KHAN and DUFF, 1973; KHAN, 1975). DUFF and ORCINO (1971) also argue that this type of technology allows an increase in labour productivity with only a slightly greater capital requirement.

The level of mechanization, to which this philosophy extends, can be either in improved hand-operated tools, animal draught equipment or in a technology based on small engines (two-wheel tractors or small four-wheel tractors, low powered weeders, threshers, winnowers, etc.). It is for this latter level of technology that the term intermediate is mostly used, especially for South-East Asian conditions, where the technical development level of the rural areas in many places is compatible with this level of technology. This is, however, not fully applicable in West Africa, where the technical capabilities of the rural areas are very low, and where any engine-powered technology will offer tremendous problems. Here, the term at present would more comply with improved hand-operated equipment or animal-drawn implements (for the savannah regions).

2.6.3. *Selective mechanization*

The philosophy of selective mechanization, sometimes called partial mechanization, argues that only certain machines, under some situations, may contribute to increased yields or may fit into the cultural, economic, employment, and production needs of the country (GILES, 1973; GILES, 1974; STOUT, 1971; STOUT and DOWNING, 1974; GEMMILL and EICHER, 1973; ESMAY and FAIDLEY, 1972; FAIDLEY and ESMAY, 1973; POTHECARY, 1970). VOSS (1975) summarizes selective mechanization as follows: 'to concentrate mechanization on those stages (or seasons) in the production-marketing process, or in the geographical area, where labour is the limiting factor (including of course those where human and animal power could not do the job at all)'. FAO (1973c) indicates that in broad terms selective mechanization means that large-scale mechanization would only be introduced at the present time in most developing countries, where it contributes to increasing employment or is necessary to break a seasonal labour bottleneck.

The basis on which the selectivity is based may differ, depending on local conditions; e.g. for tractor mechanization, areas have to be selected with fertile soils and a minimum of rocks and stumps, gentle slopes, favourable climatic conditions, and so on (STOUT, 1971); other areas will not meet the requirements for successful tractor mechanization, but might be suitable for animal power or hand cultivation (STOUT, 1971).

Selective mechanization may also prove most suitable to solve the bottleneck in a double cropping system of harvesting the first crop and getting the second planted within certain time limits. In this case selective mechanized input for these operations may be very important (FAIDLEY and ESMAY, 1973; GILES, 1974; PAL et al., 1973).

Others argue, that selective mechanization can help overcome seasonal labour bottlenecks (GEMMIL and EICHER, 1973; GILES, 1974), can increase the total labour requirements of a unit of land (INUKAI, 1970), and will be compatible with the goals of development and employment (STOUT and DOWNING, 1974). The latter authors also mention that selective mechanization can provide a 'counter-pull' to resist the attraction of the city and reduce the urban drift.

ABERCROMBIE (1972) also mentions the word selective mechanization, but more so in the sense of 'planned' mechanization, based on a sound Government policy; mechanization should be limited to what is strictly essential for meeting production targets, and would exclude any mechanization whose only purpose is to save labour, or selective mechanization in terms of particular crops.

KHAN (1972) expresses some doubts, however, as to whether in the long run the tropical farmer would accept only a selective mechanization of his operations.

The flexibility of the philosophy on selective mechanization is that it does not exclude any mechanization level and that it does accept restrictions of a socio-economic or agro-ecological nature. However, for the higher technological inputs, it does presuppose locally available expertise, which again does not generally exist in West Africa in the rural areas.

2.6.4. *Tractor hiring services*

Mechanical power applied until now in West Africa has been, through the use of standard four-wheel tractors, almost exclusively and mainly through Government subsidized and operated Tractor Hiring Units (THU). Their functioning and operation has invariably been less than satisfactory and many recommendations have been made that, instead of running the THU's, the Governments should confine themselves to subsidizing machinery and assisting private individuals to purchase tractors and equipment and set up Private Tractor Hiring Units (ANON, 1971b; GORDON, 1971; CERVINKA, 1971; PURVIS, 1968; KOLAWOLE, 1973).

PURVIS (1968) reports that for 1967, government operated tractors in Western Nigeria worked an average of 535 hours per year, while the privately owned tractors worked an average of 786 hours per year, that is 47% more than the tractors on Government THU's. Privately owned tractors, therefore, are more efficiently used, resulting in lower costs per operating hour than the government operated tractors. He reports the following figures for tractor use in percentage of total hours:

	THU tractors	private tractors
ploughing	29.9	43.7
harrowing/ridging	23.1	8.4
transporting	25.3	41.5
others	21.7	6.4
total	100.0%	100.0%

He states moreover that seasonal differences in the use of private tractors are far less marked than with the use of THU tractors.

As an interim phase of mechanization, where private farmers have neither the capital nor the technical know-how and where communal contract services have not yet come into being, Government contracting services can have application (DOWNING, 1972), but some form of private multi-farm use of tractors and associated equipment is considered to be the best solution in the long run.

The idea of private tractor hiring units has also been supported from several other sources (FAO, 1973a; MOENS, 1972, while reporting on the IRC-meeting; CHANCELLOR, 1971; CHANCELLOR, 1973; JOHNSON and LINK, 1970). WIJEWARDENE (1975), however, argues strongly against the contract tractor operator, because of the relegation of the farmer to the role of an observer with someone else doing his farming for him.

CERVINKA (1971) claims as advantages of private ownership that there is a profit motive; that there is no 'supervision' problem of tractor operations; that development and programming of farm mechanization on individual farms is done with respect to the economy of mechanized operations; that the farmer (contractor) has to pay for all tractor repairs, therefore better care is taken of tractors and equipment. As disadvantages he suggests: farmers are usually without any farm mechanization training; tractors are operating on small sized farms; the limited variety for farm machines, which has a negative influence on tractors working rate in days or hours per year; the farmer/contractor has limited financial resources for purchasing new equipment.

Some of the present problems for private THU's are that their operations are limited to basic soil tillage and seedbed preparation and that not enough alternatives are available to make sufficient useful hours per year, especially during off-season periods. GORDON (1971) suggests the following alternatives: operating road-making and road-hauling equipment; operating irrigation pumps, rice mills, corn shellers, groundnut decorticators and oil presses, corn and other crop driers, operating small circular saws, etc.; operating landcrete and sandcrete blockmaking machines, operating post-hole diggers, tree stump pullers, etc..

Another serious problem has arisen in places where private individuals have bought tractors and then have to compete with subsidized Government operated THU's (PURVIS, 1968; KOLAWOLE, 1974).

KOLAWOLE (1974) gives the following charges for 1973 for Western Nigeria in Naira per acre (1 Naira is about 1.62 dollar):

	government rate	private owners
ploughing	3.90	4.50
harrowing	1.25	2.50–3.00
ridging	1.50	2.50–3.00
planting	1.50	–

For 1975 the Government rates are reported to be (MANR, Ibadan) ₦4.50 for ploughing and ₦2.00 for harrowing and ridging.

Based on collected data, PURVIS (1968) concluded that the Government tractor hiring units were charging enough to cover their operating costs, but that the charges had to be increased by about 50% to cover their total costs (operating costs plus depreciation of equipment, buildings, etc. and supervision). It was also indicated in ANON (1971b) that the charges were enough to cover the operational costs. PURVIS (1968) calculated that for 1968 the average loss per tractor amounted to about ₦520 per tractor-year in the Government tractor hiring units.

Two-wheel tractors have only been used on a limited scale for contracting services. Perhaps a small four-wheel tractor can be considered (POTHECARY, 1970), but in general this philosophy will apply to standard four-wheel tractors.

The problems of technical capabilities will be as serious as mentioned before, but this system faces only the contractor with the problem and releases the farmer. There is no doubt, however, that if technical problems arise, the individual farmer is as much, if not more, faced with problems. Contract work with large-scale machines could become especially important and necessary for land clearing and development (ALLAN, 1975). The author argues that these should be privately owned.

2.6.5. *Large-scale farming*

Several attempts have been made by various Governments in Africa to set up large-scale mechanized projects as a way of stimulating food production and of eventually becoming self-sufficient in food supplies (FAO, 1971a).

The large areas of suitable unused land can make a philosophy of this kind understandable, but the very disappointing results of almost all of these very expensive exercises have shown that, although it may be possible to transfer physically the technology needed for such enterprises, it is not likely that the present prevailing stage of technical and management development warrant success, especially in view of the adversity of ecological parameters such as climate and soil. Unfortunately, the conclusion has been drawn in several occasions, that this type of mechanization is unsuitable and should be rejected (FAO, 1971a).

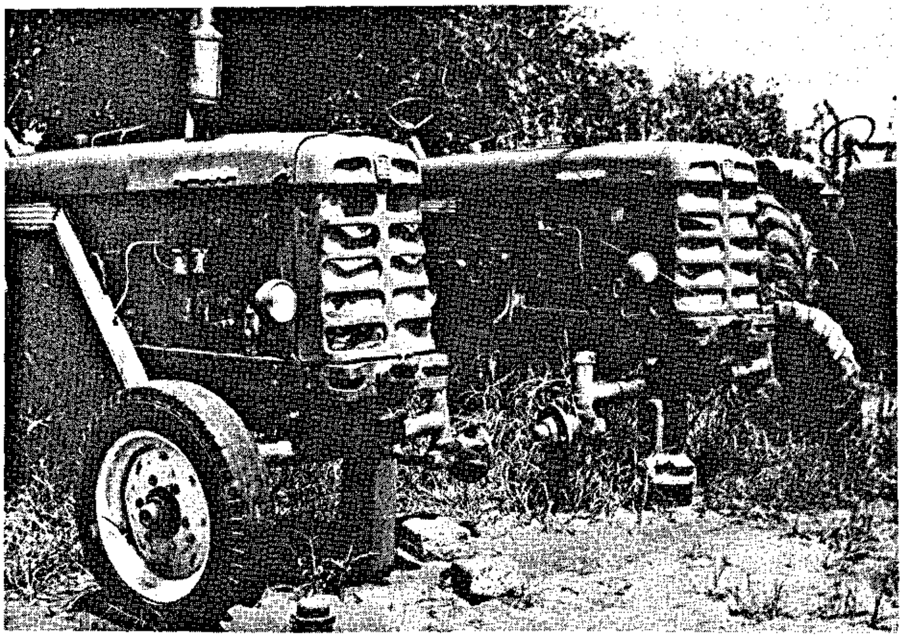


FIG. 9. Large-scale mechanization has resulted in several failures.

ANON (1971a) very strongly rejects tractor mechanization schemes because they are 'the most common and most obvious illustration of providing an answer to the wrong problem or providing the wrong answer to the right problem'. ROBINSON (1974) puts it as follows: 'I do not have much confidence in the large-scale agricultural schemes now being promoted in many countries. My own view is that the bulk of any increase in production will have to come from medium and small scale farms'. He comments, that large-scale Government projects, which at the most bring into cultivation only a few thousands hectares, will not solve the food problem, but that these requirements will only be met if several million small-holders can be motivated to increase production.

In many countries in Asia and Near East and N.W.-Africa expansion of areas is barely possible, but even in South-America or Africa where the eventual potentially cultivated area is several times the area at present cultivated, the benefit: cost ratio from the national point of view appears to be heavily in favour of making more intensive use of those parts of the continent that are already opened up (FAO, 1970b). Increasing the yield per unit area, rather than expansion of area, is considered, at least in the medium term, to be a better solution to the food problem and is stressed by CHABROLIN (1969) and DE BOER (1974).

OVERWATER (1974) also makes a critical statement about large-scale projects in stating that 'mechanization is too costly an instrument to serve as a 'show' project, however attractive this may sometimes appear from a political point of view'. This phrase could possibly be well applied to several of these projects in the emerging African nations.

A well-known example of a failure of large-scale mechanization is the groundnut scheme in Tanzania. CLAYTON (1972) summarized the mean reason for its complete failure as follows: 'mechanized clearing and motorized farming of large areas of marginal soil does not pay'. Another typical example of a failure of large-scale mechanized farming is the scheme in Northern Ghana (MULHOLLAND, 1973), which failed for reasons of poor seeds and insufficient weed control, resulting in low yields, and because the production costs were higher than anticipated. In a later stage it was also discovered that production levels could not be sustained because the soils were not very suitable in maintaining the initial chemical and physical conditions.

The latter point of sustained production levels by selecting suitable soils and by applying the appropriate crops and crop rotations to maintain the physical and chemical status of the soil, is a very important factor in planning large-scale mechanized projects, especially under upland conditions.

2.7. MECHANIZATION, AGRO-ECOLOGY AND SOCIO-ECONOMICS

2.7.1. *Introduction*

Any philosophy on mechanization will only hold for certain conditions. Crops, soils, water availability and the prevailing weather conditions on the one hand, and the people involved with their tradition and sense of economics on the other, will play an often more practical role in determining what is possible or possibly optimal under a given state of conditions and development (FAO, 1973a). In other words, the appropriate type and level of mechanization must be studied in relation to the particular circumstances not only of each country, but also of the different zones within countries and of the different farming systems (FAO, 1973c).

In the following paragraphs some of these circumstances and aspects will be touched upon briefly, thereby taking for granted the tremendous technical problems involved (as already described) in sales and after-sales support and maintenance, in land tenure and in rural development.

2.7.2. *Agro-ecological factors*

2.7.2.1. Soil and topography

Soils can limit the extent to which mechanization can be applied but they can also be improved or put under cultivation through mechanization; e.g. swampy areas with poor drainage will generally not allow for successful mechanization, nor will soils with steep slopes or soils with rocks and stumps. On the other hand, hitherto unused or under-used soils, like vertisols, heavy clay soils, soils with hardpans, etc., because of the limitations they offer to hand-hoe cultivation, can be brought under more intensive cultivation through mechanization (KELLOGG, 1975; OVERWATER, 1972).

It would be ideal, naturally, to be able to present the relation between soil types, as used in classification systems, and mechanization in terms of possibilities and problems, but correlation towards this aspects has not as yet been established. KELLOGG (1975), however, warns against too much generalization by stating that potentials for farming vary widely on similar kinds of soil, depending on the skills of the operator, the availability and prices of tools and chemicals, and local services.

That the introduction of modern techniques can lead to failures if soil conditions are not suitable or if other environmental factors are adverse is expressed by MOORMANN (1973a) and he as well as KELLOGG (1975) stresses the need for a thorough land survey and classification before efforts in mechanization are made.

OBENG (1969) proposed a soil capability for mechanized cultivation based on four factors: depth, drainage, texture and slope and differentiates eight classes.

DUDAL (1966) expressed the suitability of land for mechanization in four classes:

(1) Land suitable for mechanization. This class includes soils which have a good bearing capacity, a low to medium resistance to traction, a low slipping %, level to moderately sloping relief, good resistance to erosion and no stoniness.

(2) Land with moderate limitations for mechanization. Limitations to mechanization can be of a different nature: unsuitable physical properties of the soil, an unfavourable topography, limited economic feasibility or restrictions on the use of standard equipment.

(3) Land with severe limitations for mechanization. Severe limitations are: very steep topography, high saturation of the soils with water, land sliding, low production potential and high requirements for specialized and expensive equipment.

(4) Land with very severe limitations, or unsuitable for mechanization. These are lands, which are found in too steep topography, or for which mechanization requires very expensive equipment without having a reasonable prospect of economic returns.

RENAUT (1974) and LE BUANEC (1970) conclude from longterm trials in the Ivory Coast that mechanization is agronomically profitable, if soils have less than 5% slope, and are well protected against erosion.

MOORMANN et al. (1974) use another approach in assessing the mechanization potential for rice. They differentiate between four major agro-ecological zones for which the mechanization potential is indicated as follows:

1. Rainwater-fed lands in the high rainfall zones. Most rice is grown in a shifting cultivation pattern on soils which are usually shallow and stony and prone to rapid deterioration and erosion. It may be expected that for some time to come these soils will remain of the low input type and that in general mechanization will not be economical and that especially small-scale mechanization,

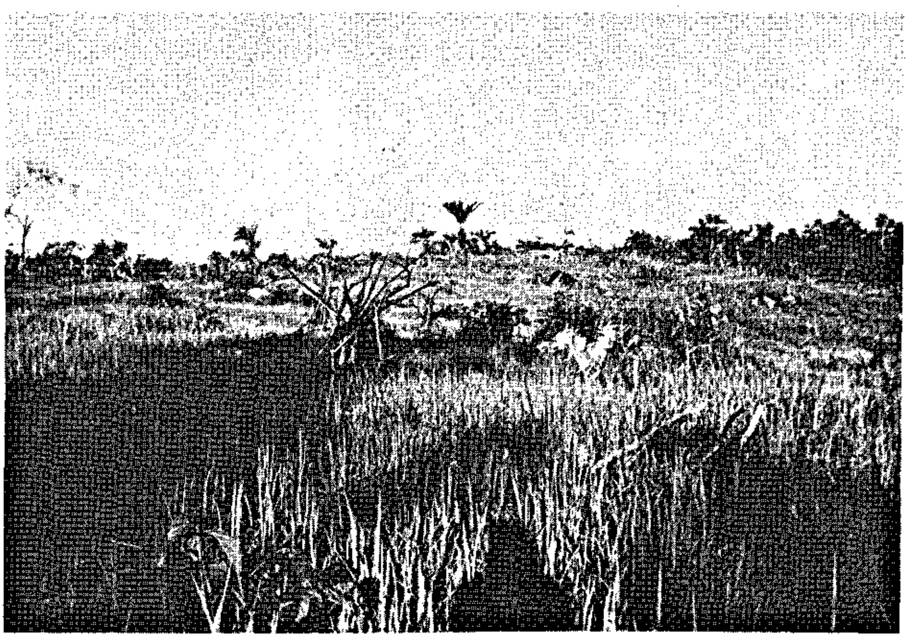


FIG. 10. Traditional upland rice field.

based on two-wheel tractors, will not be feasible. There are limited areas of flatter land on coastal and interior formations. Prospects for mechanization on these lands in the derived savannah zones are better in view of lower costs of clearing and tillage, but unless suitable rotations with high-yielding crops can be found, mechanization will not be feasible.

2. Hydromorphic land in minor valleys and inland swamps. Many of these valleys are small and prone to short duration floods; under the natural conditions of seasonal flooding, mechanization in any form will be difficult. Improvement of the water-economy by constructing dams, by levelling and bunding can make mechanization a reasonable proposition. However, most of these valleys will be too small for large-scale mechanization and small-scale mechanization could be a possible answer.
3. Major inland valleys and depressions. The crucial factor in these areas is water management. Damming the water in the rivers to prevent excessive flooding and to provide irrigation water will be a necessity to make optimum use of these lands. This broad landtype is undoubtedly most suitable for intensive mechanization of rice cultivation, either by large-scale mechanization on large farms or by small-scale mechanization or tractor hiring units on small and medium farms.
4. Coastal plains, including the mangrove areas. Where there are problems of salinity and of potential acidity the potential is limited, unless the land can be

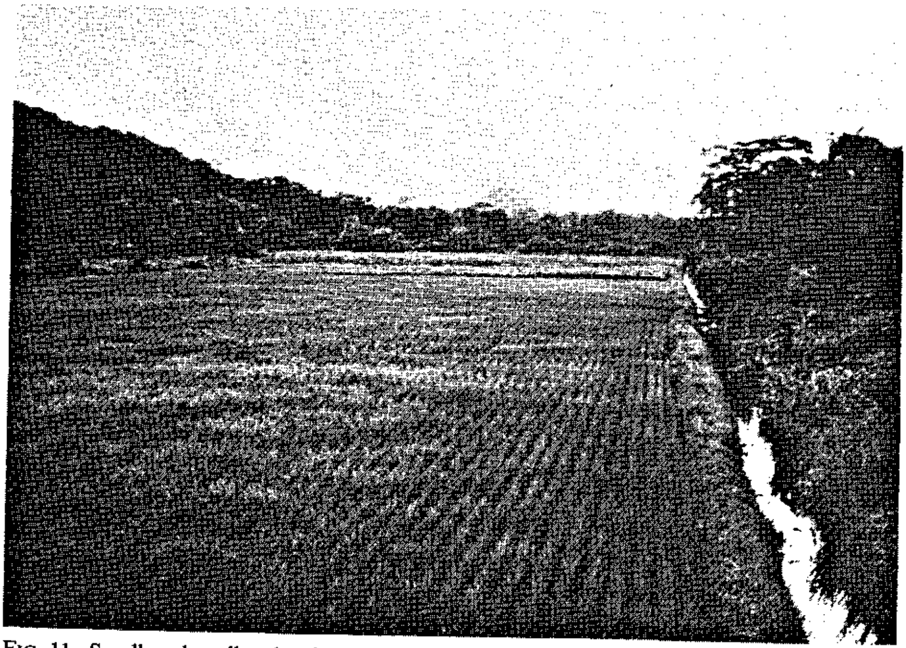


FIG. 11. Small-scale valley development for rice growing.

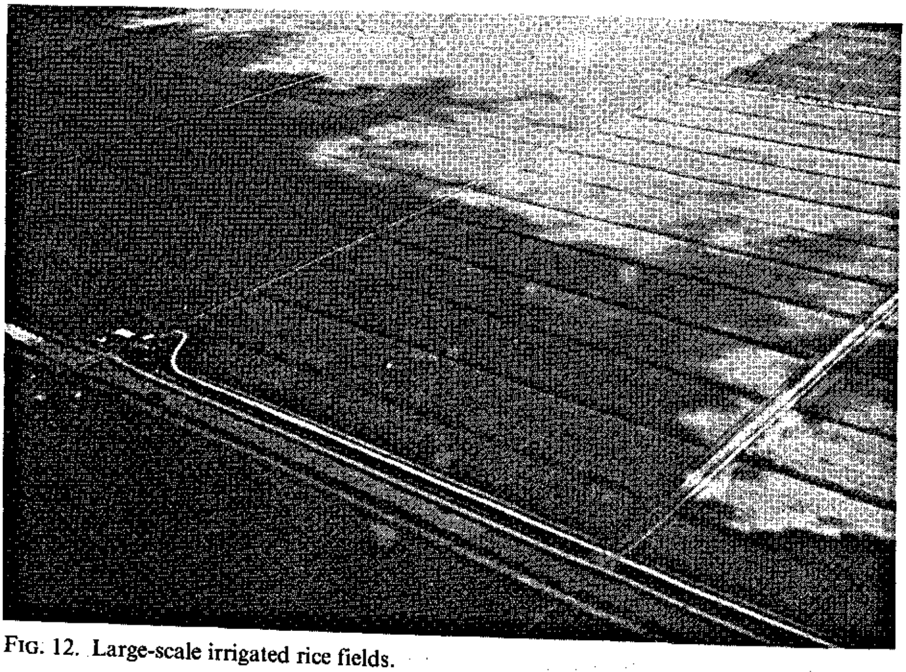


FIG. 12. Large-scale irrigated rice fields.

empoldered and fresh water is available. Where these problems do not exist large-scale mechanization has a great potential.

For these marine coastal plains, of which the potential is demonstrated in Surinam, Pons (1972) gives the following soil requirements for successful mechanization:

1. farms should be established on soils with even land surface;
2. plough layers and other upper horizons should not contain peat and should have rather low contents of organic matter;
3. the soil permeability should be at most moderate;
4. the soils should have at least slow internal water permeability;
5. the soil or the plough-sole should have sufficient bearing capacity;
6. the plough layer should develop a good structure that is stable enough, at least for the greater part, to stand light puddling and the soils should have some structure development in the deeper horizons also;
7. the soil pH under wet conditions should be suitable for rice growth;
8. to be suitable for mechanized rice cultivation, soils should have a known fertility level (preferably at least moderate) as well as known fertility requirements for the envisaged rice crop.

Overwater (1974), discussing the same area, states that the soil has to be a heavy soil, not too permeable and preferably not bottomless; that the terrain has to be level and that field sizes should not be too small for efficient mechanization.

For West Africa, it is expected that the major impact of mechanization in the years to come will be in developed hydromorphic areas, where double cropping with steady high yields can be obtained continuously, without serious erosion problems or decline in soil fertility (Curfs and Rockwood, 1975; Harms, 1972).

2.7.2.2. Crop and climatic conditions

Cash crops will naturally offer better prospects for mechanization than subsistence crops. A clear example is the use of knapsack sprayers by local farmers in the cocoa-belt in Nigeria, almost exclusively to spray cocoa, which has been the major cash crop for many years.

Clayton (1972) indicates that it is obvious that with low-value crops, the increase in yields must be substantial to justify the cost of mechanical cultivation.

A crop increasingly becoming important as a cash crop is rice. Ruthenberg (1971) lists some factors on which the expansion of wet rice cultivation is based; namely it permits constant land use, without decline in yields; it produces high, certain yields per hectare and consequently allows the concentration of people; it enjoys a relatively favoured position within traditional agriculture; manufactured goods like mineral fertilizer, herbicides, and implements make wet-rice cropping more productive. Finally, it is claimed that even the rational use of the traditional production factors of soil and water can produce a relatively high yield.

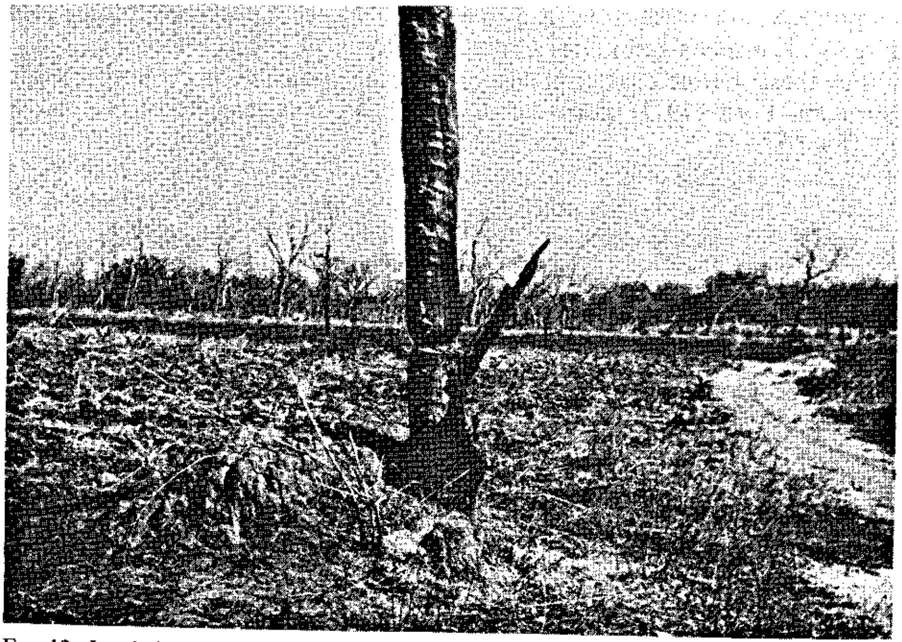


FIG. 13. Land clearing in a savannah area.


FIG. 14. Land clearing in a tropical rainforest.

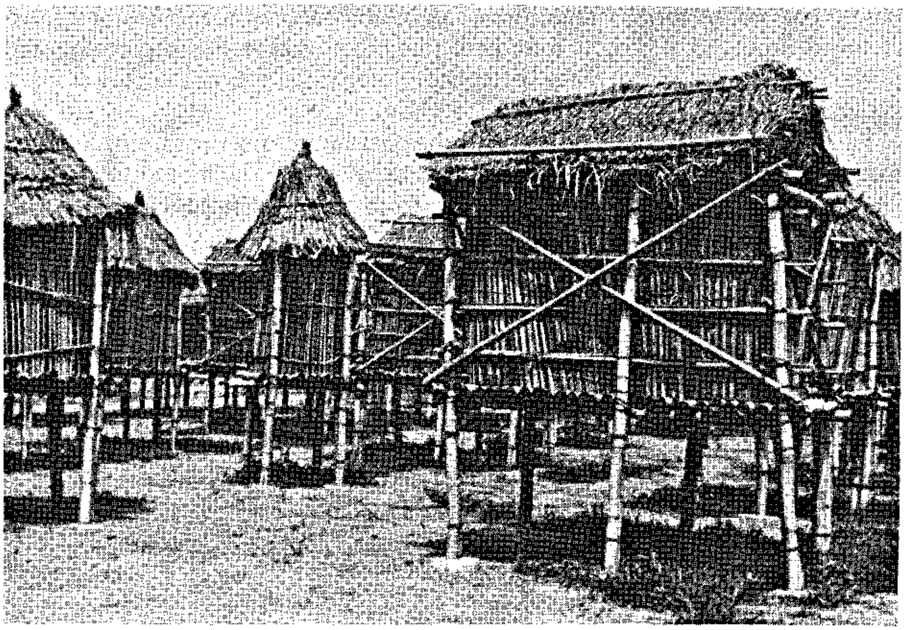


FIG. 15. Low-cost storage structures under testing.

Rice, however, is a labour consuming crop, and grows best on lands where most other crops do not grow well, i.e. the low-lying hydromorphic and valley-bottom soils. Of all crops in the humid parts of West Africa it is expected that mechanization will progress most with rice, if the other necessary technological inputs, like water control measures, fertilizers, etc. are also available and applied (CURFS and BOSHOFF, 1975).

For the savannah areas also other cereals, such as wheat and maize, can become attractive for mechanization, as well as groundnuts, which have since long been a major cash crop for many areas in the savannah region. RAMOND et al. (1970) remark in relation to this, that new techniques are more readily accepted for the new cash crops than for food crops or crops that have been grown for a long time. In this case, the farmer has long been aware of the risks involved and is reluctant to run further ones.

In comparing the savannah with the tropical rain-forest in West Africa one can expect mechanization to progress faster in the savannah area, because the population density in general is lower, the timing of the operations becomes more critical as the rainy season is shorter and land clearing is much less of a problem (FAO, 1966b). However, in this region water supply is more critical and for successful mechanization either large areas are required or irrigation systems have to be developed to grow a second crop.

In the high-rainfall zone the timing of the operations can also be of importance. Too wet or too dry conditions can inhibit successful application of mechanical inputs at the right time (soil tillage and harvesting especially) and power mechanization can make better use of the available time than lower input systems.

Last, but not least, is the question of the post-harvesting operations. Mechanized inputs for drying and storage will be required in the humid tropical regions before full benefit can be achieved from increased production, and this will demand additional capital investment.

2.7.3. *Socio-economic factors*

2.7.3.1. Economics of scales of mechanization

In this paragraph some calculations will be presented with the aim of indicating by means of a consideration of costings, which level of mechanization is most economical with varying farm sizes. The present price levels in Nigeria are used for the calculations.

In view of the variability in possible costs and input hours for various operations, a low and a high level for each was chosen, as presented below.

	costs/prices	input hours/ha
level	($)	
manual	low 0.20/hr	low 200
manual	high 0.40/hr	high 400
two-wheel tractor	low 1,500,–	low 30
two-wheel tractor	high 3,000,–	high 50
four-wheel tractor	low 6,000,–	low 3
four-wheel tractor	high 10,000,–	high 6

The actual calculations are given in Appendix I, and the results summarized in Figs. 16 and 17. Fig. 16 indicates the cost per hour with different hours used per year for three levels of mechanization and Fig. 17 gives the relation between

TABLE 3. Comparison of different levels of mechanization in terms of minimum input hours per year and minimum area required to become economically justified over hand-operations (figures indicate the break-even points).

	Manual labour					
	low inputs, low costs			high inputs, high costs		
	hrs/yr	ha/yr	cost/ha	hrs/yr	ha/yr	cost/ha
Two-wheel tractor:						
high inputs, high costs	430	8.6	173	640	12.8	128
low input, low costs	220	7.3	88	340	11.3	68
Four-wheel tractor:						
high inputs, high costs	250	41.7	99	375	62.5	75
low imputs, low costs	135	45.0	52	190	63.3	38

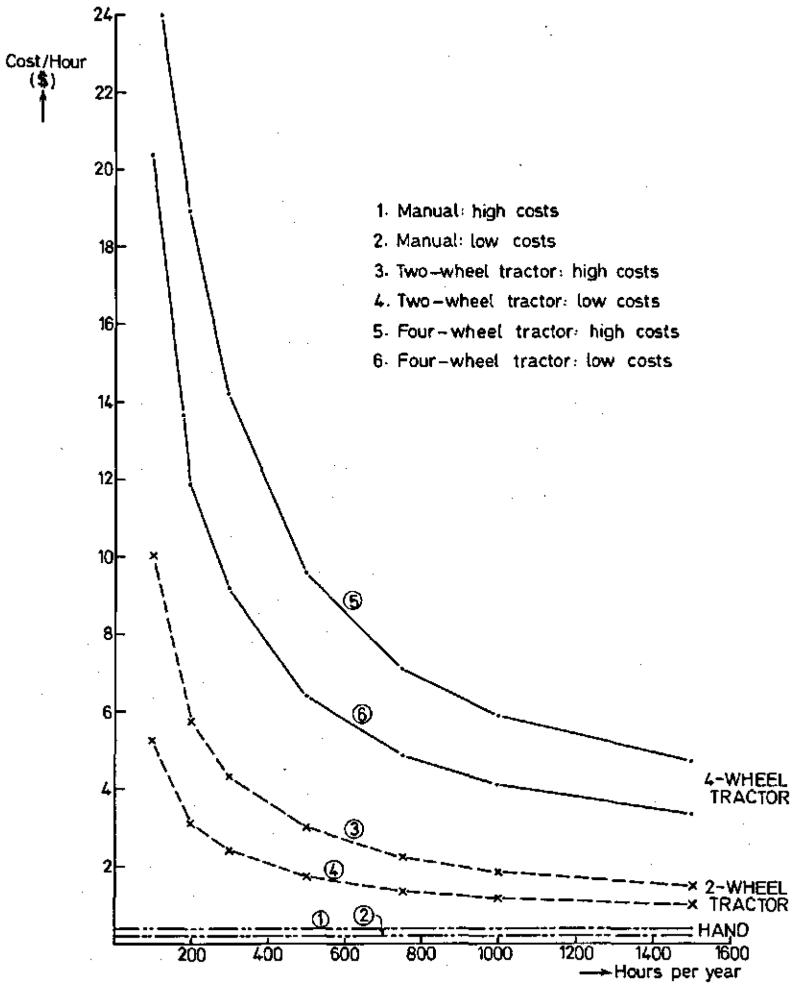


FIG. 16. Relation between cost per hour and the number of hours used per year for different levels of mechanization under high and low cost levels.

cost per ha and different hours used per year for the case of land preparation (primary plus secondary tillage).

Table 3 shows at how many hours and hectares per year mechanical cultivation becomes less expensive than hand-operations.

The average values, where the answer in Nigeria at present will probably lie, are for a two-wheel tractor 408 hrs/year or 10.0 ha/year at a cost of 114 dollars/ha, while for a four-wheel tractor they are: 238 hrs/year or 53.1 ha/year at a cost of 66 dollars/ha.

These calculations and results are based on one crop a year, which means that under double-cropping the minimum area required for economic justification can be halved and will be about 5 ha for a two-wheel tractor and 27 ha for a

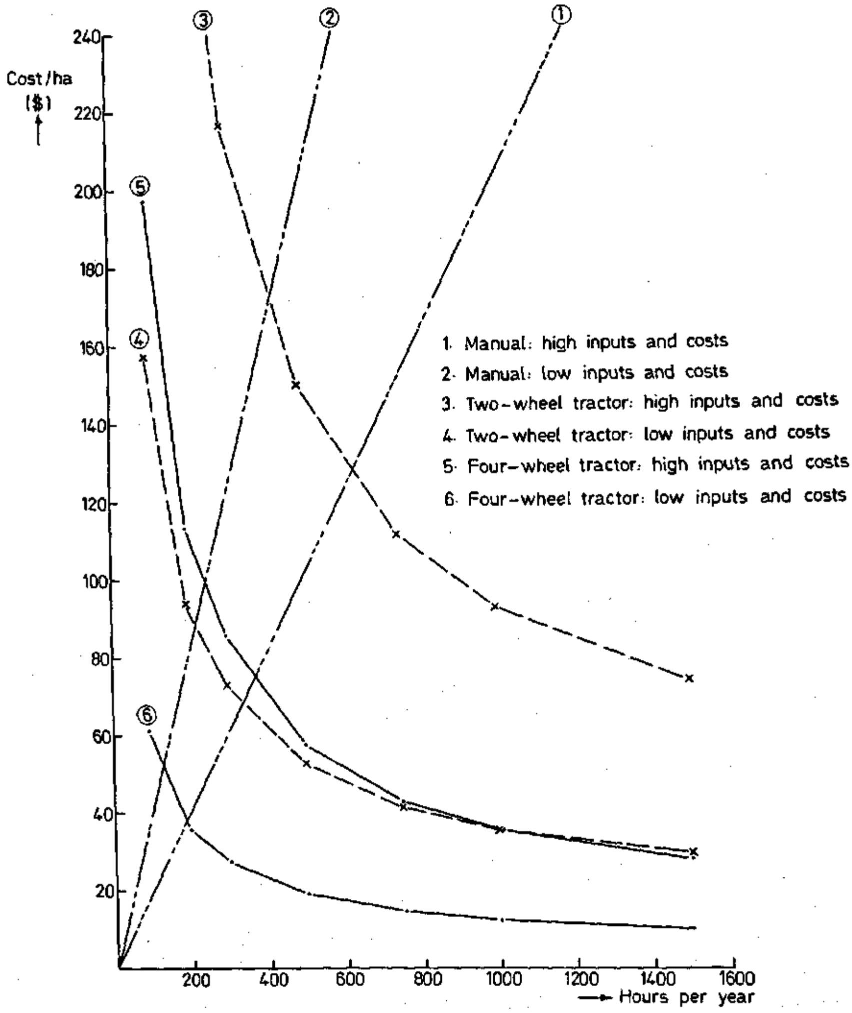


FIG. 17. Relation between cost per hectare and the number of hours used per year for different levels of mechanization under high and low cost and input levels.

four-wheel tractor. Two-wheel tractors (with low inputs and low costs) are economically justified over four-wheel tractors (with high inputs and high costs) if the input hours per year are less than 1000. This means around 33 ha for the two-wheel tractor and 167 ha for the four-wheel tractor: the cost for each is then about $35/ha.

Some conclusions from these calculations are that:

- higher labour prices will stimulate mechanization;
- the alternatives low costs/high inputs and high costs/low inputs are about equal in terms of costs/ha;

– double-cropping will stimulate mechanization;
– a two-wheel tractor has substantially lower costs per hour, but its costs per ha are in general higher than for a four-wheel tractor.

2.7.3.2. Ergonomical aspects

The working capacity of an individual is limited and primarily determined by the capability of supplying sufficient oxygen and taking sufficient food (ZANDER, 1973). The same author indicates that an energy consumption of 20.0 kJ (= 4.8 kcal) per minute, excluding a basal metabolic rate of about 4.2 kJ (= 1.0 kcal) per minute, is the maximum consistent level that an adult man should be expected to expend; rest pauses should be included, if the average level exceeds this level.

STAUDT (1975) uses the maximum oxygen intake of a person as a criterium for the working capacity, since the energy consumption is limited in the first place by the restricted capacity for oxygen intake by the human body. The values measured usually vary from 2 to 5 liters of 0_2 per minute.

MOENS et al. (1974) use another value to indicate what may be expected from a working man, namely that for an 8-hour working day the tolerance limit is about 30 pulses per min. above the rest level.

How much work a man can actually do in a given situation depends on various factors: his physical condition and psychological state, the climatic conditions, notably temperature, relative humidity and sunshine, the place where he works and the way he works.

VOSS (1975) reports from a FAO-study, that, at temperatures of 25 °C, output may be considered as normal, but that, as humidity and temperature rise, output will decline; at temperatures of 34 °C human productivity will be at least 50% below normal. STAUDT (1975) concludes from studies among forestry workers in Surinam, that the working capacities of labourers in developing countries are lower than in developed countries.

That the ergonomical aspects can be important, when new technology is introduced, was shown in an ergonomical study on different types of small tractors at I.I.T.A., Ibadan, Nigeria (DIBBITS, 1975). Some of the conclusions of this study were that, in general, operating two-wheel tractors (4.4–7.4 kW) under upland and irrigated conditions resulted in a higher, and mostly unacceptable, workload than traditional land preparation with a hand-hoe; that the working and the steering system influenced the workload most; that in general rotary tilling was less tiring than ploughing and that operating a small four-wheel tractor (10.3 kW) did not result in unacceptable ergonomical constraints, as was also indicated by CURFS (1974b).

2.7.3.3. Social attitudes

A few remarks will be made on the social attitude of farmers in West Africa to accept new technology.

Migration from the rural areas to the cities in West Africa has been indicated by several authors. FAO (1973c) estimated that the growth of the urban popu-

TABLE 4. Percentage of family members migrating from the farm family by age group (IITA, 1971)

Age group (years)	Three savannah area villages	Three forest area villages
1–10	10	8
11–20	35	49
21–30	30	19
31–40	11	1
41–50	1	–
50 or more	–	–

TABLE 5. Rate of migration from the farm of those in each education level (IITA, 1971)

Rate of migration for those with:	Three savannah area villages	Three forest area villages
no schooling	6	7
primary school non-graduate	–	5
primary school graduate	84	75
secondary school non-graduate	11	100
secondary school graduate	100	100
West African School Certificate	100	100

lation in Africa was about 5% annually during the 1960's and indicated that these urban growth rates are likely to accelerate over the period 1970–1985, due to increased migration. FLINN et al. (1974) mention that most farmers now complain of labour shortages, due partly to high rates of exodus from rural areas. OLUWASANMI (1975) indicates that the typical migrant is younger and better educated than the rural population from which he originates. This is confirmed by village studies in Western Nigeria (IITA, 1971). Tables 4 and 5 are taken from these studies to illustrate these phenomena.

To stop the migration of young people from the rural areas to the cities something has obviously got to be done or changed either in terms of economic prospects and/or in making life and farming in the rural areas more acceptable to the farmers-to-be.

Mechanization, it is contended, can be one of the factors in achieving this, especially if applied selectively in terms of operations and crops (STOUT and DOWNING, 1974), but also in terms of machines. A machine, when introduced, may well be rejected if it offers more ergonomical restrictions than the present hand-operations. This fact may become a limiting factor in the introduction of two-wheel tractors for example, which can offer serious ergonomical disadvantages if not selected well (see par. 2.7.3.2). In this respect a difference in acceptance of two-wheel tractors may be expected between farmers of South-east Asia and farmers in West Africa. In South-east Asia a two-wheel tractor often serves as a replacement of oxen power and is in this respect an improvement, while in West Africa, especially where there has been no bullock power with all the consequences involved, a two-wheel tractor is just as new an introduction as a four-wheel tractor.

Another aspect of this may be the introduction of simplified, stripped-down machines, which may be rejected for reasons of social status, even though the price may be considerably lower than well-dressed machines.

2.8. Mechanization and employment

In almost all places in the world where new technological inputs were introduced, the employment question has been under heated discussion. It is therefore not unusual that the effect of agricultural mechanization on employment in the developing countries is now in the picture and that arguments for and against mechanization are being made.

There is no doubt that mechanization can create serious social and unemployment problems and can result in serious labour displacement, if not applied judiciously.

In general, technical innovations will create socio-political-cultural change (Kranzberg, 1972) and also agricultural mechanization cannot suddenly develop as a result of external technical assistance without certain internal changes evolving in the country (Smerdon, 1971).

The major argument is not whether more food has to be produced in the developing countries and that a certain intensity or form of mechanization will therefore be indispensable, but the question as to the type and intensity of mechanization that will meet the production targets and at the same time reduce labour displacement to a minimum seems to be the crucial issue (FAO, 1970; FAO, 1972a; Smerdon, 1971; Reeser, 1975; Abercrombie, 1972; Stout and Downing, 1974; Giles, 1974; Esmay, 1971; Gemmill and Eicher, 1973).

Hopfen (1969) argues that improved hand and animal tools can lead to fuller employment of the rural labour force.

Advocates of selective mechanization (see par. 2.6.3) argue that meaningful and selectively applied mechanization will make double-cropping possible and therefore result in increased labour utilization; it will also eliminate labour bottlenecks during peak periods and result in a more even annual labour distribution. Abercrombie (1972) proposed selective mechanization also in terms of crops, so that restrictions would be placed on mechanization in the case of those which at present make the largest contribution to employment.

Advocates of intermediate technology (see par. 2.6.2) argue that it will eliminate labour bottlenecks, especially in double-cropping systems, but that also local manufacturing will result in new job opportunities.

FAO (1972b) differentiates between four types of employment resulting from local manufacture:

a) direct employment in the manufacturing operation;
b) backward-linked employment with the manufacturing plant, through the ancillary industries which supply the plant;

c) forward-linked employment with the manufacturing plant, through the distribution of the product, the selling of it and any repairs and maintenance;
d) peripheral employment as a result of the demand on goods and services which arise from industrialization, e.g. banking facilities, urban housing, transport, food services, government services.

Although there are some reports that mechanization can result in increased on-farm employment (ALI and AGRAWAL, 1974; DONDE, 1972; SINGH, 1973; MICHAEL, 1972; ESMAY, 1971; INUKAI, 1970), especially in areas where expansion of area or increased cropping intensity can occur, it is to be accepted that even with a good mechanization policy, there will be some replacement of labour at the farm level (FAO, 1972b), especially during the introductory stages (ABERCROMBIE, 1972). VOSS (1975) indicates that with the introduction of improved handtools (stage I) and/or draught animals (stage II), there is not likely to be any question of displacing labour, and that rather overall labour requirements are increased. He argues that with the introduction of tractors (stage III) labour may be replaced at some stages of the farming cycle. He states further 'it would be difficult to find instances where mechanization has actually displaced labour in the developing areas of Africa, south of the Sahara, contrary to areas in Pakistan and some Latin American countries'.

DUFF (1975) concluded from surveys in the Philippines, that mechanization has had only a limited effect on employment. He stated 'the examination of the labour use data for rice production indicated a change in the pattern of labour used, but little increase in overall employment, at least on a per hectare basis'.

Animal power is reported to decrease if tractors are introduced (SINGH, 1973; MICHAEL, 1972; ALI and AGRAWAL, 1974).

Other technological improvements and introductions, if combined with mechanization, will reduce the risk of creating unemployment or more underemployment. Especially irrigation is cited as being employment-creating (ANON, 1968; RUTHENBERG, 1971), as well as the acceptance by farmers of the new seed-fertilizer technologies (KHAN, 1972; KELLOGG and ORVEDAL, 1969; BORLAUG, 1972; YUDELMAN, 1971). Studies by BARKER et al. (1973) in the Philippines did not show any major labour displacement due to the introduction of mechanization and they stated 'reduced labour requirements for land preparation have been more than offset by increased labour requirements for weeding and harvesting and threshing'. This indicates, that employment opportunities with high yielding crops and irrigation under good management practices will rather increase than decrease and that proper mechanization under these conditions will generally not result in labour displacement. This will hold especially, if the best lands are exploited first for mechanization developments (DOWNING, 1972; KELLOGG, 1975).

One difference between the developed and the developing nations should be borne in mind. Industrial development preceded or ran parallel with agricultural development in most developed countries, while in many developing countries this is not the case. And as pointed out by ABERCROMBIE (1972) the creation of new industrial jobs is the principal key to the solution of problems of employment and under-employment.

In this respect, industrial development obviously has a direct bearing upon alternative employment opportunities and will affect mechanization developments in the rural areas. For the time being, Governments could perhaps regulate technological developments by way of subsidies or taxes, not only on machines but also on all other inputs necessary to make the move towards commercial agriculture, without generating serious unemployment.

2.9. Selection of appropriate mechanization systems: a discussion

There is no doubt that for any situation there is an appropriate, optional and justified level of technology, which will fit the socio-economic and agro-ecological conditions, whilst it increases food production and provides better living conditions for the farming population.

How can this be visualized and realized for the humid parts of West African subsistence agriculture in the years to come?

In Fig. 18 some inter-relationships are indicated, which do have a direct bearing upon any move from subsistence farming to commercial agriculture.

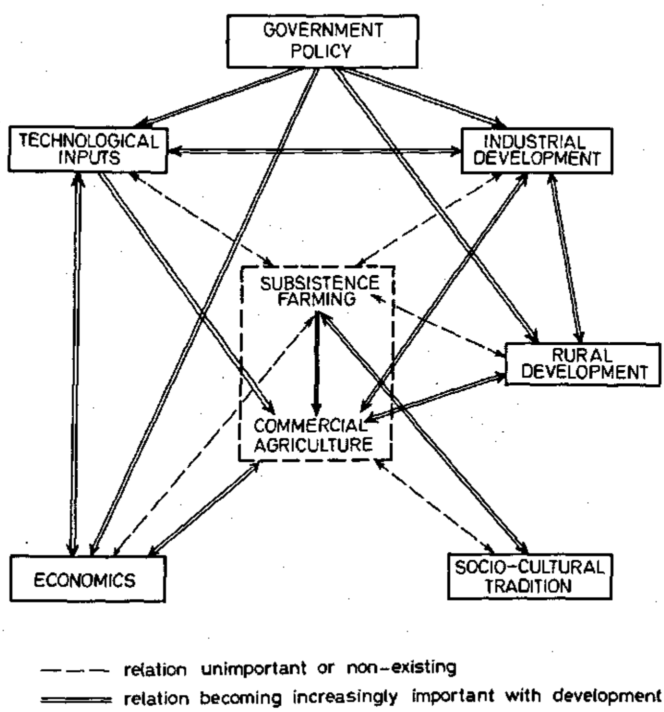


FIG. 18. Factors affecting the change from subsistence farming to commercial agriculture.

These relationships and factors will be considered first, before mechanization alternatives, as indicated in Fig. 19, can be discussed.

It is assumed in this discussion that mechanization cannot take place unless agriculture transcends the stage of pure subsistence farming and becomes commercial.

Government policy, industrial and rural development, socio-cultural traditions and price relationships, as well as the availability and applicability of the whole package of technological inputs are much interwoven and cannot be separated from mechanization developments.

Government policy is probably the most important factor in negotiating and stimulating any new development and this holds true for agriculture and mechanization. As far as mechanization is concerned, a government can have an effect in stimulating rural development (education, roads, marketing arrangements, electrification, etc.), agricultural industries, subsidies on tools and equipment, inducing a spare parts policy and so assuring after-sales service, effecting favourable produce-inputs price relationships, and so on. In this way it also holds a powerful tool in directing which crops will be mechanized first, whether an extension of an area (through Government subsidized land clearing and developing units) or intensification of existing land will occur and the extent to which scale and level of mechanization can become most important: it is also the only apparatus which can intervene in the present land tenure system, which holds many limitations for mechanization developments.

Assuming a 'sound' Government policy, mechanization may develop as discussed below. In the initial stages of agricultural development money has to be generated to set the train in motion; Government is probably the most appropriate instigator of this. This reflects the idea of many Governments in the field of mechanization by setting up Tractor Hiring Units. The initiation of mechanization and making farmers aware of its existence and possibilities by this means, seems appropriate for the West African situation. Handing over to private individuals must, however, be done as quickly as possible. One big advantage of (private) tractor hiring units in these initial stages is that the operations requested for by farmers will be chosen deliberately and selectively, indicating that the most essential operations and crops will be mechanized first, without displacing too much labour or disrupting the system.

With the move to better lands, especially hydromorphic areas and valley bottoms, and with the introduction of new varieties and fertilizers, while at the same time rural and industrial development starts to grow, a technical capability and a demand for improved hand-operated and small-engine operated equipment can be envisaged. At this stage local manufacturing or assembling of this equipment may start at a modest scale (intermediate technology).

As irrigation develops and the chemicals (herbicides and insecticides) may start playing a role, combined with the fact that the rural-urban migration has resulted in seasonal labour shortages, several alternatives can be chosen by farmers as indicated in Fig. 19:

1. continued use of private hiring units;

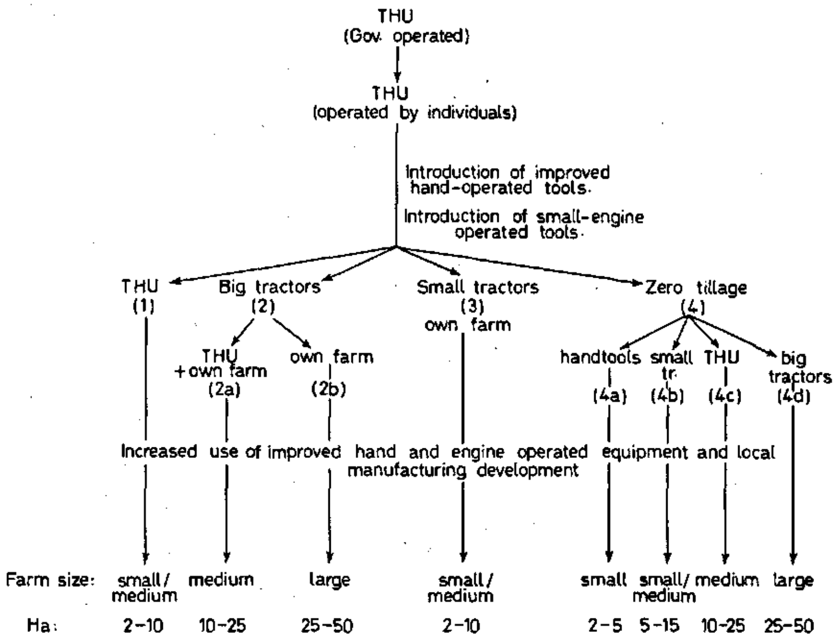


FIG. 19. Introduction of mechanization and mechanization alternatives in tropical West African agriculture.

2. buying a big tractor, either for his farm alone (2a) or in combination with hiring work (2b);
3. buying a small tractor, to be used on his own farm;
4. another alternative, probably for upland soils, if zero tillage practices prove to be suitable, could be to either supplement this technique with hand-tools

(4a), a small tractor (4b), a tractor hiring unit (4c) or a big tractor (4d).

These alternatives could be visualized for the following approximate farm sizes:

alternative	farm size	ha
1	small/medium	2–10
2a	medium	10–25
2b	large	25–50
3	small/medium	2–10
4a	small	2–5
4b	small/medium	5–15
4c	medium/large	10–25
4d	medium	25–50

Since a local manufacturing capability and industry cannot be developed overnight, it may be foreseen that imported technology will play the major role initially, while the local manufacturing industry with its products will come in at

FIG. 20. Rice is becoming an important cash crop.

a later stage. This will naturally deserve all conceivable support in order to reach as many small farmers as possible.

The issue of large-scale versus small-scale mechanization still remains.

So far small tractors have only been introduced on a very limited scale and not enough studies have yet been made to assess their potentialities for West African agriculture and it is therefore with little doubt that standard four-wheel tractors will keep playing the major role in providing additional power to human energy in the short and medium term. In the long run one could visualize two-wheel tractors being applied for some specialized crops like rice or vegetables in market gardening, but because of the relatively high costs per hectare and the ergonomical constraints, one might expect a small four-wheel tractor, with a wider application, higher capacity, less ergonomical restrictions, and lower costs per hectare, to have better prospects and offer less restrictions in terms of acceptability. However, there is reason to believe that in the long run the major impact of mechanization will come through the use of standard four-wheel tractors; this could be realized through privately owned tractor hiring units or through neighbour hire work from the medium to big farmers who own a tractor. In this way small farmers could also benefit through the tractor hiring services, supplemented in their farming activities with their own hand-powered and/or engine-powered modern tools and equipment. It is therefore in this last field of improved hand/engine-powered equipment, as a supplement to basic operations done by hiring services, that agricultural engineering research could make the most progress.

If, in this proposed pace of development, Governments would regulate labour costs and prices well, mechanization could be introduced and extended selectively and appropriately, stimulating local manufacturing (with perhaps eventual assembly plants for four-wheel tractors as is now the case with certain types of automobiles), with the provision, however, that this will eventually lead to local manufacturing and reduce the risks of serious unemployment or underemployment. With the present rural-urban migration going on and the availability of much unused land, the employment issue in many places in West Africa, however, is not critical, compared to South-east Asian conditions; mechanization as part of the agricultural development might to some extent even keep people in the rural areas, thereby releasing women and children from farming work.

Lastly, one can visualize mechanization development to progress most quickly for cash crops, especially rice and vegetables, and for the best suited soils, where double-cropping can be practised, especially hydromorphic soils and valley bottoms.

Finally, despite all the prospects for better use of labour, soil and water and technology, most of the farming in West Africa is, for many years to come, likely to remain of a subsistence type with hand labour as the main power source; a 'Green Revolution' with inherent seed-fertilizer technology will have to be set in motion first.

3. MODEL STUDIES ON MECHANIZATION SYSTEMS

3.1. Introduction

As indicated in Chapter 2, mechanization is not a problem in itself, but an inter-related part of agricultural development.

To study mechanization and mechanization systems per se, one has to isolate mechanization aspects from environmental factors. This can be done through model studies, which are a simplification of reality (DE RIDDER, 1974) and which require that boundaries be drawn to insulate the system components of interest from external disturbing influences (VARSHNEY, 1975).

In this chapter two model studies on mechanization are presented.

The first study relates to rice growing with different systems of mechanization and the effect on labour requirements. This study is based on, or derived from, existing data on time and labour requirements for the different field operations in producing and harvesting rice.

The second study relates to vegetable growing, in which various vegetable crops and rotations are grown in the field under two mechanization levels, one based on manual labour and one based on a small four-wheel tractor.

The main purpose of these model studies is to determine which operation(s) in the production and harvesting process for the different mechanization levels is (are) most limiting to an increased area under cropping in terms of labour requirements. In the second study on vegetables, an economic analysis is also made to evaluate the economic consequences of replacing manual labour by tractor-power.

3.2. Rice mechanization study

In this part use was made of available information on time and labour requirements for the various operations of producing rice at different mechanization levels (CURFS, 1972 and CURFS, 1974a). The operations taken into account are: tillage, planting, weeding, fertilizing, harvesting, transportation and threshing; excluded are working hours involved in water management, bunding, supervision and in travelling to and from the field. It was assumed that high-yielding, insect and disease free rice was grown, which yielded the same for all systems, about 3.5 ton per hectare.

The timing of the operation was taken as follows:

- primary tillage: 2–3 weeks before planting;
- secondary tillage: 0–1 week before planting;
- transplanting: 0–1 after secondary tillage, with nursery preparation at 3–4 weeks before transplanting;
- direct seeding: 0–1 week after secondary tillage;

- weeding: manual weeding at 3 and 6 weeks after planting; rotary weeding at 2 and 5 weeks after planting, supplemented by a manual weeding at 8 weeks after planting; chemical weeding before emergence and at 3 weeks after planting;
- fertilizing: just before secondary tillage (P and K); just after weeding 3 and 6 or 2 and 5 weeks after planting (1/3 N and 1/3 N); at heading, which is 11 weeks after transplanting and 13 weeks after direct seeding (1/3 N);
- harvesting: 4–5 weeks after 50% heading;
- transportation: 0–1 week after harvesting;
- threshing: 1–2 weeks after harvesting.

3.2.1. *Results*

Although numerous steps can be identified in the development process from purely manual labour inputs to mainly mechanical inputs, seven steps (systems) were arbitrarily chosen for this study.

A summary of these seven steps is given in Table 6.

The labour calendars of these seven steps are presented in Fig. 21 I-VII.

Step I shows various labour peaks: soil tillage, transplanting and weeding,

TABLE 6. Labour requirements of the various operations in producing rice for seven mechanization systems.

Operation	I	II	III	IV	V	VI	VII
Tillage	hoe	hoe	hoe	rotill	rotill	rotava	rotava
	300	300	300	35	35	7	7
Planting	transp.	transp.	dibbl.	dibbl.	drilling	drilling	drilling
	320	320	80	80	10	10	2
Weeding	manual	rotary	rotary	rotary	chemical	chemical	chemical
	350	150+75	150+100	150+75	20	20	2
Fertilizing	manual	manual	manual	manual	manual	manual	tractor
	20	20	20	20	20	20	4
Harvesting	sickle	sickle	sickle	sickle	binder	combine	combine
	87.5	87.5	87.5	87.5	10	3	3
Transportation	manual	manual	manual	trailer	trailer		
	70	70	70	35	12		
Threshing	manual	pedal	pedal	thresher	thresher		
	120	70	70	35	35		
Total hours	1267.5	1092.5	877.5	517.5	142	60	18
% tillage	24	27	34	7	25	12	39
% weeding	28	21	28	43	14	33	11
% till+weeding	51	48	63	50	39	45	50
% planting	25	29	9	15	7	17	11
% harv/tra/thre	22	21	26	30	40	5	17

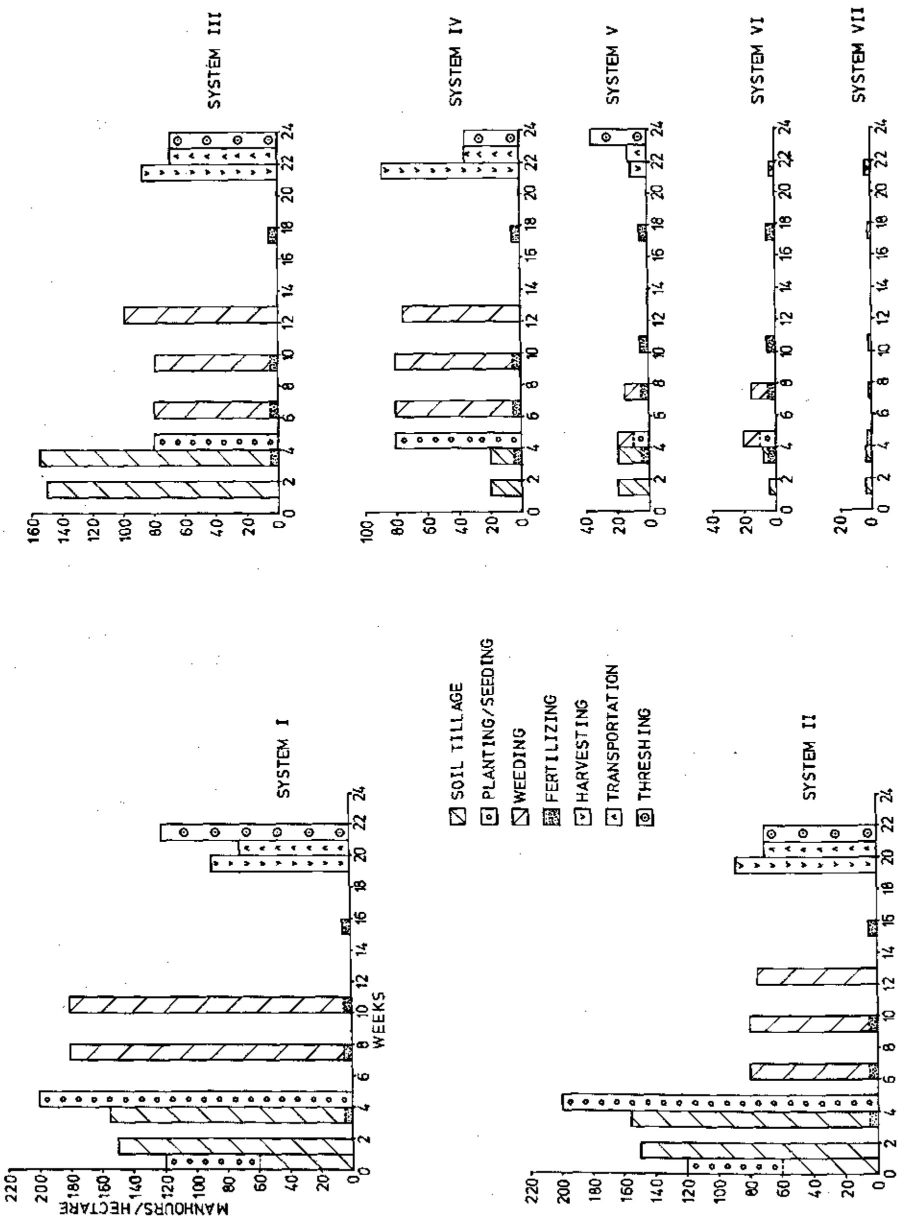


FIG. 21. Labour input calendar for seven steps in mechanization development for rice.

and also, but to a lesser extent, harvesting and threshing. Rotary weeding in step II reduces the weeding labour peak, while in step III direct seeding instead of transplanting eliminates the planting peak. In step IV a rotary tiller, instead of manual soil tillage, eliminates the tillage peak; the small tractor can also be used for transportation and threshing. In this step, however, planting, weeding and also harvesting have become bottlenecks. In step V, these bottlenecks are reduced by drilling, chemical weed control and binder harvesting. In step VI a four-wheel tractor with rotavator is used for soil tillage and the rice is harvested by combine-harvester. Step VII is completely mechanized.

3.2.2. *Discussion*

Rice production poses several bottlenecks. Transplanting is an important one, but can be replaced by direct seeding methods without any major mechanization inputs. A *conditio sine qua non* for this change, however, is good water control and levelled land. As can be seen from Table 6, transplanting can take up 25–30% of the total labour requirements. Harvesting and threshing may also pose problems, especially if soil tillage and weeding are mechanized and harvesting and threshing only partially; ultimately only one or other way of combine-harvesting can eliminate these bottlenecks.

In most indicated steps soil tillage and/or weed control are the major bottlenecks. These operations claim between 40 and 60% of the total labour requirements for all steps. These figures show that, whatever the mechanization system is, soil tillage and weed control will remain limiting operations.

MAKANJUOLA (1974) has indicated the same problems for the cultivation of upland rice, for which crop he estimates seedbed preparation to take about 30% and weeding to take about 18% of the total labour requirements. Identical results are also illustrated for groundnuts (FAO, 1972c), in which soil tillage and weed control together require 220 hrs per ha or 46% of the total hours for entirely manual cultivation, while these figures are resp. 119 hrs or 38% for animal draught cultivation, 56.5 hrs or 32% for partially powered mechanization and 8.5 hrs or 28% for fully powered mechanization.

FLINN (1974) reported data from farm surveys in Western Nigeria, which indicated that weeding especially is the major consumer of labour, taking an average of 52% of the total labour requirements in the derived savannah belt and an average of 72% in the cocoa belt; he also mentioned that hired and contract labour were largely used for weeding and also to a lesser extent for land preparation (heap making).

3.3. FIELD STUDY WITH VEGETABLES

The previous study was done mostly on a theoretical basis, whereby approximate averages of available labour data were used or derived.

In this field study with vegetables, time and labour requirements were measured in the field for all operations, except for irrigation, which was given once a week during the dry season, and for travelling time to and from the field. The study was done with different vegetable crops and rotations under two systems; the first system was based on manual labour exclusively, while the second system was based on a small four-wheel tractor of 10 kW (14 HP), with a clearance of about 48 cm, and supplemented, where necessary, with manual labour.

The study was carried out on plateau soils and the plot sizes were 300 m^2 for the first system and 1100 m^2 for the second system. There were no replications. However, the use and applicability of this type of model study was demonstrated by the field work.

Field crops and crop rotations used in the study were:

rotation 1: (1.1) okra (H39); (1.2) French beans (local selection), using the okra plants as stakes; (1.3) French beans (local selection) with artificial stakes; (1.4) musk melon (Burpee's Hybrid); (1.5) tomato (H9–1);

rotation 2: (2.1) tomato (Marzanino); (2.2) sweet corn (USDA 34); (2.3) sweet potato (local selection); (2.4) okra (H39);

rotation 3: (3.1) leaf vegetable (Amaranthus ITLV8); (3.2) leaf vegetable (Celosia ITLV8); (3.3) sweet corn (USDA 34);

rotation 4: (4.1) hot pepper (TCA 14);

rotation 5: (5.1) sweet corn (USDA 34); (5.2) tomato (H9–1); (5.3) leaf vegetable (Celosia ITLV8).

In rotation 1 the French beans were grown on half the area without land preparation and using the remaining okra stakes as support, while on the other half the land was tilled and the beans supported by artificial stakes. In rotation 2 sweet potato was interplanted with the sweet corn about one month before harvesting the sweet corn. The tomatoes were grown using artificial stakes and additional mulching with rice straw was done in rotation 2 only.

All crops were grown applying standard cultural practices; crop residues were left on the surface and managed as mulch as well as possible.

In this study cost analyses were also done, based on the measured inputs and outputs. Prices and costs, as prevailing in Nigeria, were used for the calculations (Appendix II).

3.3.1. *Background information*

'Migration from rural to urban areas has increased the pressure for intensive food production near cities. The lack of rapid transportation facilities, adequate storing and processing facilities makes it necessary to produce perishable commodities such as vegetables at as short a 'time distance' as possible from the market' (IITA, 1973). Market gardening in and around cities may therefore become of increasing importance in most countries in West Africa.

Mechanization from developed countries is usually suitable for pure stand systems and only on a very limited scale for traditional mixed cropping systems (WILSON, 1975). BRADFIELD (1972) has demonstrated that mechanization can be successful for intercropped systems, which are one of the best techniques for gaining time to grow more crops.

Although the main purposes of this field study were to detect which crop production processes were most limiting for the two systems and to look at the profitability of the two systems, a modest, and only preliminary, attempt was also made to view the practical application of mechanization in intercropping in a few cases (rotation 1 and 2).

The small four-wheel tractor of 10 kW (14 HP) was used in this study for two main reasons. The first reason was that, as expressed by several authors (DOWNING, 1972; WADHWA, 1969; ABERCROMBIE, 1972), small tractors could possibly find application in market gardening and vegetable growing and therefore no standard size four-wheel tractor was used. In addition it may be assumed that market gardening and vegetable growing will not be done on fields big enough to justify a conventional four-wheel tractor. The second reason was that, in initial trials with vegetables using a two-wheel tractor of 7 kW (10 HP), several limitations of this type of tractor had occurred. At closer row spacings this tractor could only be used to a limited extent for inter-row weeding, and the steering stability while weeding was low. In addition, the field efficiency while working with this tractor was also low, about 40–50% for soil tillage operations with time requirements of about 40 hrs/ha for ploughing. The main reason for the relatively low efficiency and capacity was the need for the operator to rest; resting during tillage operations accounted for about 20–25% of the total working time. From an ergonomic point of view this tractor had therefore serious disadvantages, which proved to be much less for the small four-wheel tractor that, because of its relatively high clearance, could also be applied well for inter-row weeding.

3.3.2. *Yields*

The yields of the two systems are given in Table 7. Tractor cultivation (15–20 cm) resulted in most cases in considerably higher yields than manual cultivation (3–5 cm) on the plateau soil. The deeper tillage provided a better medium for the plant roots to develop and the plants therefore grew better.

Some crops with a stronger and deeper rooting system, such as hot pepper and also tomato, however, yielded generally higher following the shallow hand-hoeing. For tomato an additional possible explanation might be that in crop 2.1 additional mulch was applied and that in crop 5.2 following the sweet corn a considerable amount of crop residue was left on the surface, while crop 1.5, where no such mulch or crop residues remained, yielded lower following hand-hoeing. The mulch on the surface, which conserves water and thus can help to improve crop growth and yield, might therefore have had a positive effect on the tomato yields. This might also explain why the leaf vegetables yielded higher following manual cultivation in crop 5.3 after the tomato crop, which left a lot of crop residue and not in crop 3.1 and 3.2 when no (or only small) amounts of crop residues were left.

It should be mentioned, however, that the trial was not replicated and that

TABLE 7. Yields following manual and tractor systems (fresh weight in kg/ha)

Crop number	Growing season	Manual system	Tractor system
1.1	wet	3,572	5,276
1.2	wet	3,356	3,351
1.3	wet	3,961	5,261
1.4	dry	2,387 (4,467 melons)	13,158 (15,158 melons)
1.5	wet	7,760	11,061
2.1	wet	18,587	15,595
2.2	wet/dry	2,726 (13,659 cobs)	7,896 (36,248 cobs)
2.3	dry	9,606	15,423
2.4	wet	6,655	7,107
3.1	wet	407	2,096
3.2	wet/dry	24,740	43,788
3.3	dry/wet	7,523 (32,967 cobs)	7,339 (33,662 cobs)
4.1	wet/dry/wet	18,240	12,317
5.1	wet	5,180 (25,933 cobs)	6,550 (27,048 cobs)
5.2	dry	47,713	38,622
5.3	wet	73,953	71,703

FIG. 22. Land preparation with a hand-hoe.

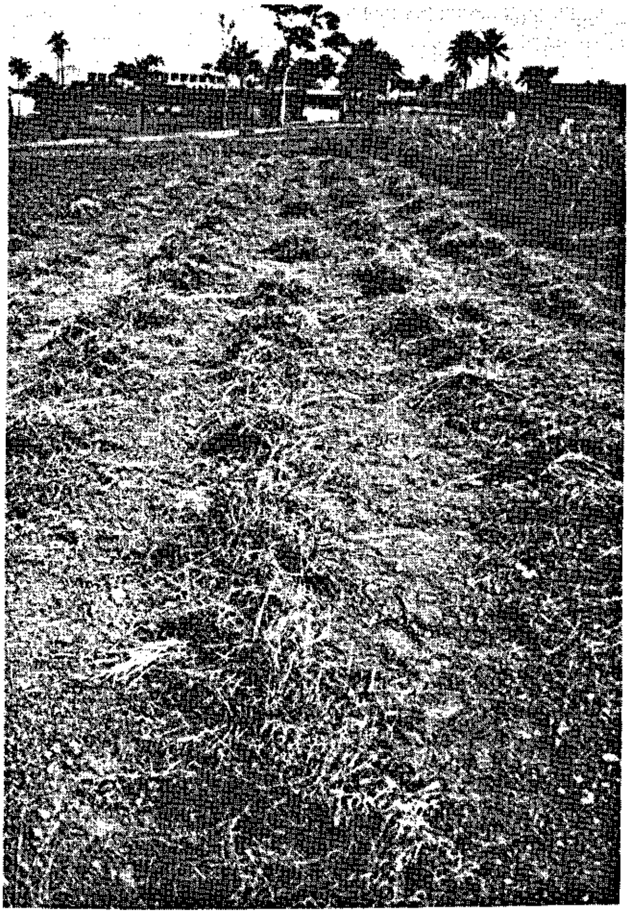


FIG. 23. Land after hand-hoe preparation.

variations in yield might therefore have been due to varying soil conditions as well.

3.3.3. *Labour requirements and labour productivity*

Labour inputs were recorded for all field operations. The results are given in Tables 8 and 9 for the manual and tractor systems respectively. Labour requirements for the various vegetables depended on the crop with especially hot pepper and tomatoes requiring very high labour inputs. The total input hours were substantially reduced by using a tractor. For the manual systems soil tillage especially and, even more, weeding are very labour demanding and form together an average of about 50% of the total input hours. Harvesting in the manual systems took an average of about 20% of the total hours. For the tractor system the situation was different, in that soil tillage and weeding took an average of 28% of the total hours. These figures indicate that in manual systems soil tillage and, even more, weed control are the major limiting factors for in-

TABLE 8. Input hours for manual systems (hrs/ha)

Crop number	Total input hours	Tillage %	Weeding %	Tillage + weeding %	Spraying %	Harvesting %
1.1	1842	27.8	31.7	59.4	3.0	20.2
1.2	1367	–	66.5	66.5	2.3	25.1
1.3	2611	–	36.0	36.0	0.8	19.2
1.4	704	24.7	39.8	64.5	12.4	6.0
1.5	5514	14.1	19.0	33.1	5.2	6.9
2.1	4165	9.9	25.7	35.6	5.1	20.7
2.2	1103	26.5	39.4	65.9	–	3.1
2.3	1418	–	64.0	64.0	–	17.1
2.4	1624	26.4	27.2	53.6	0.5	28.7
3.1	996	59.3	33.9	93.3	–	3.8
3.2	1709	28.4	18.3	46.7	–	42.4
3.3	1899	14.2	55.5	69.7	–	7.7
4.1	11901	4.7	26.8	31.5	0.4	62.3
5.1	1712	40.2	30.1	70.3	1.6	11.4
5.2	5765	5.5	22.2	27.7	8.6	18.2
5.3	2376	21.7	27.7	49.5	0.7	29.8

TABLE 9. Input hours for tractor systems (hrs/ha)

Crop number	Total input hours	Tillage %	Weeding %	Tillage + weeding %	Spraying %	Harvesting %
1.1	810	3.1	16.4	19.5	6.6	67.9
1.2	1228	–	54.1	54.1	2.6	29.5
1.3	1398	2.1	27.7	29.7	2.4	42.6
1.4	424	6.0	21.8	27.8	33.7	12.5
1.5	4824	0.5	34.7	35.1	5.8	6.9
2.1	2521	1.4	9.7	11.1	7.0	29.8
2.2	232	13.2	19.0	32.2	–	27.2
2.3	930	–	21.3	21.3	–	37.1
2.4	1154	2.0	43.9	45.9	0.5	49.7
3.1	391	6.6	45.1	51.8	4.2	24.6
3.2	817	3.6	1.7	5.3	–	81.6
3.3	434	8.7	4.6	13.2	–	25.3
4.1	9873	0.5	12.6	13.0	0.3	78.8
5.1	468	6.8	33.1	19.9	6.8	32.1
5.2	3742	0.9	19.7	20.6	10.9	20.9
5.3	1781	0.9	31.0	32.0	0.5	54.8

creasing the area under cropping, while in tractor systems the major bottleneck is harvesting, but weeding may also be a problem, if the tractor cannot be used for inter-row cultivation and manual weeding has to be done. Herbicides were applied in a few instances with one application by knapsack sprayer requiring

TABLE 10. Labour replacement by tractor system

Crop number	Total manhours		Tractor hours	Manhours replaced	
	Hand-system	Tractor system		by one tractor-hour	per ha
1.1	1842	440	44.0	23.5	1032
1.2	1367	1228	–	–	–
1.3	2611	1398	37.7	32.2	1213
1.4	704	424	35.7	7.9	280
1.5	5514	4824	35.2	19.6	690
2.1	4165	2521	34.3	47.9	1644
2.2	1103	232	48.6	17.9	871
2.3	1418	930	8.1	60.2	488
2.4	1624	1154	26.3	17.9	470
3.1	996	391	39.1	15.5	605
3.2	1709	817	43.4	20.5	892
3.3	1899	434	57.4	25.5	1465
4.1	11901	9873	62.0	32.7	2028
5.1	1712	468	53.2	23.4	1244
5.2	5765	3742	34.6	58.5	2023
5.3	2376	1781	30.5	19.5	595
	Average (1.2 excluded):		39.3	28.2	1036

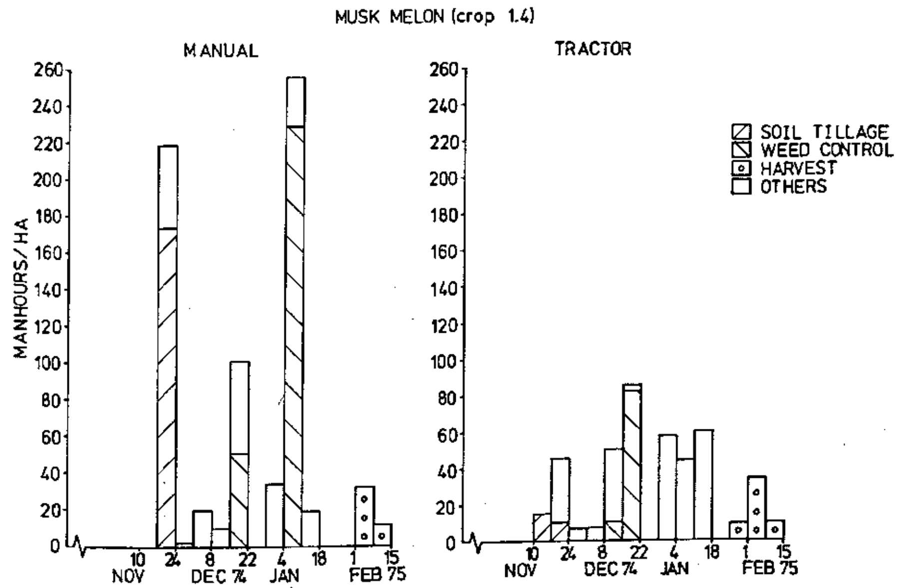


FIG. 24. Labour input calendar for musk melon following manual and tractor cultivation.

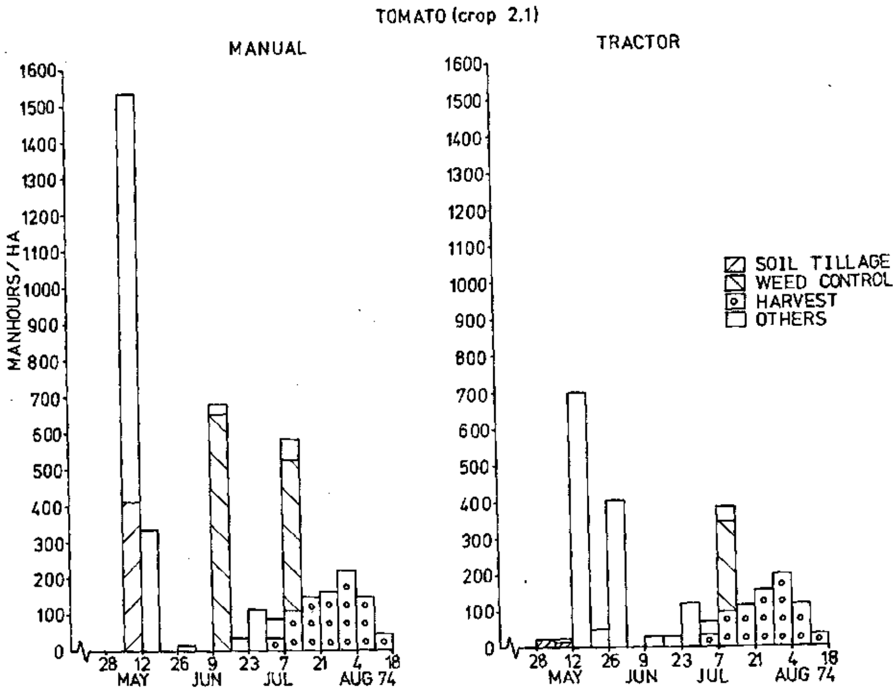


FIG. 25. Labour input calendar for tomato following manual and tractor cultivation.

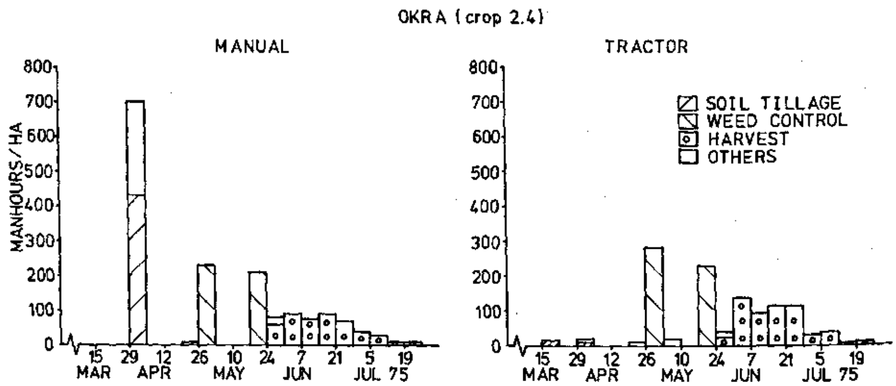


FIG. 26. Labour input calendar for okra following manual and tractor cultivation.

about 10–20 hrs/ha, thus reducing the labour input for weed control considerably. The effect of tractor input on total labour requirements and labour replacement is indicated in Table 10. On average, about 28 manhours are replaced by one tractor-hour. The tractor could be used in land preparation and weeding for about 39 hours on average for all crops, replacing about 1000–1100 manhours per hectare.

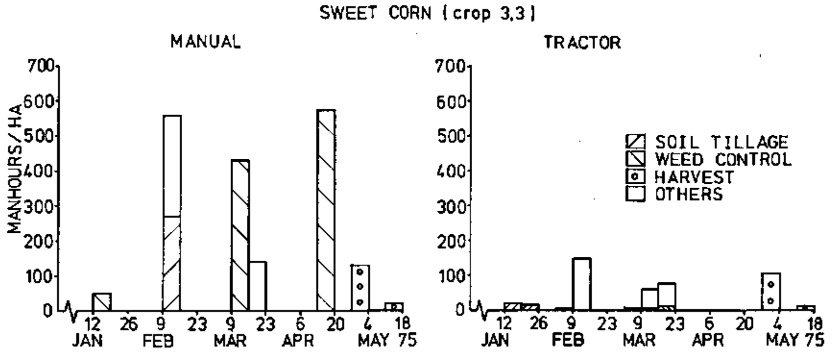


FIG. 27. Labour input calendar for sweet corn following manual and tractor cultivation.

TABLE 11. Labour productivity following manual and tractor systems.

Crop number	Manual system kg/man hour	Tractor system kg/man hour
1.1	1.94	6.51
1.2	2.46	2.73
1.3	1.52	3.76
1.4	3.39	31.07
1.5	1.41	2.29
2.1	4.46	6.19
2.2	2.47	34.09
2.3	6.77	16.58
2.4	4.10	6.16
3.1	0.41	5.37
3.2	14.48	53.57
3.3	3.96	16.90
4.1	1.53	1.25
5.1	3.03	14.00
5.2	8.28	10.32
5.3	31.13	40.26

Typical examples of the effect of tractor use on the labour input calendar are given in Figs. 24, 25, 26 and 27. Labour productivity in kg produce per manhour input was for most crops considerably higher under the tractor system (Table 11).

3.3.4. *Production costs*

The cost figures of the manual and tractor systems are given in Tables 12 and 13. In general, the total costs of the manual system are higher than those of the tractor system; the total costs minus the labour costs, which are the costs a farmer has to pay for equipment, fertilizers, herbicides, etc., are however higher for the tractor system, as could be expected.

TABLE 12. Costs of manual system ($/ha)

Crop number	Total costs	Total costs minus labour costs	Total costs				
			Till. %	Weed. %	Tillage + weeding %	Spraying %	Harvest %
1.1	773	128	23.2	26.4	49.7	10.0	16.8
1.2	572	93	–	61.5	61.5	6.3	21.0
1.3	1006	92	–	36.1	36.1	3.0	17.5
1.4	429	183	14.2	22.8	37.0	33.5	3.4
1.5	2230	300	12.2	17.9	30.1	11.8	5.9
2.1	1655	197	8.7	22.7	31.3	10.1	18.2
2.2	456	70	22.4	41.0	63.5	–	2.6
2.3	496	–	–	64.0	64.0	–	17.1
2.4	653	81	23.0	23.7	46.7	2.1	25.0
3.1	363	15	57.0	32.6	89.5	–	3.7
3.2	633	35	26.9	17.2	44.1	–	40.1
3.3	772	107	12.2	52.6	64.8	–	6.7
4.1	4398	232	4.4	25.4	29.8	1.7	59.0
5.1	693	94	34.7	26.0	60.7	4.8	9.9
5.2	2392	374	4.7	18.7	23.4	17.1	15.3
5.3	1019	187	17.7	22.6	40.4	1.7	24.3

TABLE 13. Costs of tractor system ($/ha)

Crop number	Total costs	Total costs minus labour costs	Total costs				
			Till. %	Weed. %	Tillage + weeding %	Spraying %	Harvest %
1.1	603	316	18.7	19.3	38.0	12.7	31.9
1.2	528	98	–	51.3	51.3	6.8	24.0
1.3	711	222	18.5	22.6	41.1	5.2	29.3
1.4	500	352	22.7	15.6	38.3	–	3.7
1.5	2137	449	4.7	31.5	36.3	12.2	5.4
2.1	1209	295	12.4	7.1	19.5	12.2	21.7
2.2	356	275	37.9	32.7	70.5	–	6.2
2.3	361	36	–	29.1	29.1	–	33.4
2.4	595	191	17.4	29.8	47.2	2.2	33.7
3.1	364	227	31.6	33.0	64.6	7.7	9.2
3.2	552	266	24.4	12.1	36.5	–	42.3
3.3	466	314	36.5	20.2	56.7	–	8.3
4.1	4120	664	4.8	14.9	19.8	1.6	66.1
5.1	487	324	29.1	26.4	55.5	7.4	10.8
5.2	1814	504	8.6	14.2	22.8	20.0	15.1
5.3	1013	390	7.2	31.5	38.7	1.4	33.7

TABLE 14. Production costs in $/kg following manual and tractor systems.

Crop number	Manual system	Tractor system	Tractor system in % of manual system
1.1	0.22	0.11	50
1.2	0.17	0.16	94
1.3	0.25	0.14	56
1.4	0.18	0.04	22
1.5	0.29	0.19	66
2.1	0.09	0.08	89
2.2	0.17	0.05	29
2.3	0.05	0.04	80
2.4	0.10	0.08	80
3.1	0.89	0.17	19
3.2	0.03	0.01	33
3.3	0.10	0.06	60
4.1	0.24	0.33	138
5.1	0.13	0.07	54
5.2	0.05	0.05	100
5.3	0.01	0.01	100

The production costs in terms of the costs of producing one kilogram of produce were considerably lower for most crops under the tractor system (Table 14).

3.3.5. *Returns and profitability*

Prices of vegetables vary a great deal over the year and marketing information on the fluctuations of vegetable prices was not available for this area. There was also no information available on the correlation between market prices and off-farm prices.

For the purpose of this study market prices were collected a number of times and in several locations. Off-farm prices were estimated as 60–70% of the market prices. This resulted in the mean high and low prices as used in the calculations. (Table 15)

TABLE 15. Range of estimated off-farm prices of vegetables.

Vegetables	Off-farm prices ($)
Leaf vegetable	0.10–0.30 per kg
Tomato	0.30–0.60 per kg
Okra	0.30–0.60 per kg
Hot pepper	0.50–1.00 per kg
Sweet corn	0.03–0.06 per cob
Sweet potato	0.05–0.15 per kg
Musk melon	0.20–0.60 per melon
French beans	0.30–0.60 per kg

TABLE 16. Gross and net income from growing vegetables under manual systems with high and low price levels.

Crop number	Produce value ($/ha)		Profit ($/ha)[1]		Net income ($/hour)[2]	
	low	high	low	high	low	high
1.1	1072	2143	299	1370	0.16	0.74
1.2	1007	2014	435	1442	0.32	1.05
1.3	1188	2377	182	1371	0.07	0.53
1.4	893	2680	464	2251	0.66	3.20
1.5	2328	4656	98	2426	0.02	0.44
2.1	5576	11152	3921	9497	0.94	2.28
2.2	410	820	–46	364	–0.04	0.33
2.3	480	1441	–16	945	–0.01	0.67
2.4	1997	3993	1344	3340	0.83	2.06
3.1	41	122	–322	–322	–0.32	–0.24
3.2	2474	7422	1841	6789	1.08	3.97
3.3	989	1978	217	1206	0.11	0.64
4.1	9120	18240	4722	13842	0.40	1.16
5.1	778	1556	85	863	0.05	0.50
5.2	14314	28628	11922	26236	2.07	4.55
5.3	7395	22186	6376	21167	2.68	8.91

[1] Profit ($/ha) = Produce value per ha – Total costs per ha
[2] Net income ($/hour) = Profit/Total input hours per ha

TABLE 17. Gross and net income from growing vegetables under tractor systems with high and low price levels.

Crop number	Produce value ($/ha)		Profit ($/ha)		Net income ($/hour)	
	low	high	low	high	low	high
1.1	1583	3166	980	2563	1.21	3.16
1.2	1005	2011	477	1483	0.39	1.21
1.3	1578	3157	867	2446	0.62	1.75
1.4	3032	9095	2532	8595	5.97	20.27
1.5	3318	6637	1181	4500	0.24	0.93
2.1	4679	9357	3470	8148	1.38	3.23
2.2	1087	2175	731	1819	3.15	7.84
2.3	771	2313	410	1952	0.44	2.10
2.4	2132	4264	1537	3669	1.33	3.18
3.1	210	629	–154	265	–0.39	0.68
3.2	4379	13136	3827	12584	4.68	15.40
3.3	1010	2020	544	1554	1.25	3.58
4.1	6159	12317	2039	8179	0.21	0.83
5.1	811	1623	324	1136	0.69	2.43
5.2	11587	23173	9773	21359	2.61	5.71
5.3	7170	21511	6157	20498	3.46	11.51

Gross and net income for the vegetables under the manual and tractor systems are presented in Tables 16 and 17.

For most vegetables the tractor system resulted in a higher net income per hour than the manual system; for hot pepper, however, the net income was a little higher following the manual system, while for tomatoes there was not much difference.

In general, net farm income rose when vegetables were grown during the dry season.

3.3.6. *Discussion*

The results of this model study indicate that, in general, growing vegetables on well-drained plateau soils under the tractor system results in higher yields, lower costs and higher net income per manhour of labour input than under the manual system. The higher yields are mainly due to better land preparation and the lower costs due to the saving of labour; on an average, using a tractor saved about 1000 manhours of labour per ha. The relatively high labour wages in Nigeria have acted favourably for the tractor system.

Tillage and weed control were generally, both in terms of input hours and costs, the most important and limiting operations.

In the manual system tillage and weeding together took on average 54% of the total input hours, while these operations accounted for about 48% of the total costs. In the tractor system these figures were 28% and 42% respectively. In the

FIG. 28. Mechanical weed control can only be effective if done timely (okra).

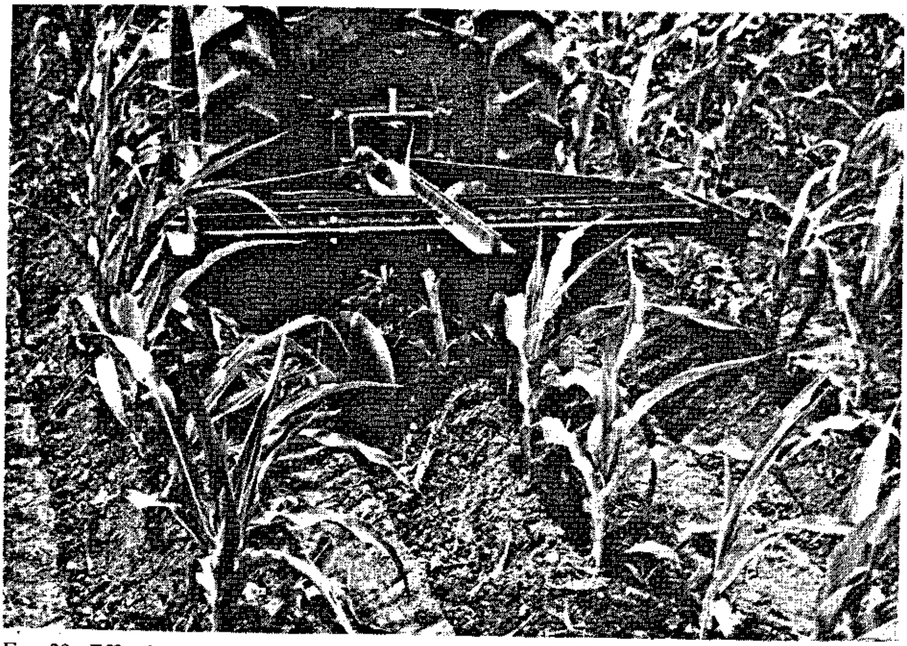


FIG. 29. Effective mechanical weed control (sweet corn).

manual system tillage and weeding were equally limiting and serious bottlenecks, while in the tractor system weeding was far more important than tillage, especially when inter-row weeding with the tractor could not be done. It should be mentioned that also harvesting can be a limiting factor for several of these vegetables, although this is usually spread out over several subsequent operations.

An important factor emerging from this study is the increase in yields, which can occur for most crops through tractor cultivation. Identification of these crops which react favourably to deeper tractor cultivation and of those crops which can react more in favour of minimum tillage, is therefore important. This is illustrated in this field study, in which most crops reacted positively to deeper tillage, while crops like hot pepper and also tomato, especially if crop residues or mulches were available, reacted positively to minimum tillage. It may also be concluded from these results that tillage effects should not be looked at per se, but also in relation to the amount of mulch available on the surface and the season.

4. SOIL TILLAGE

4.1. Introduction

As shown in Chapter 3, soil tillage and weed control are the major limiting factors in the crop production process. For this reason and for the fact that most of the mechanized inputs in West Africa so far have been in the field of soil tillage, it was decided to carry out soil tillage studies in depth in this mechanization study. Soil tillage investigations may also indicate which power source might be the most desirable and soil tillage recommendations can therefore have a direct effect on the level and type of mechanization.

In this study the effects of different land preparation practices were investigated in four places along a typical toposequence. The major effects measured were yields, weed growth differences as a result of the different tillage treatments (Chapter 5), plant growth characteristics, and some soil chemical and physical properties and changes.

4.2. General indication of the prevailing soils

The soils studied are derived from basement complex and most of the well-drained upland soils belong to the large group of Paleustalfs (USDA, 1974), Luvisols (FAO, 1970a) or Sols ferrallitiques (INRA, 1967).

Along a typical toposequence three main groups of soils can be differentiated:

I. Plateau soils (convex)
II. Lower slope soils (concave)
III. Valley soils (hydromorphic).

The main characteristics of these groups are indicated in Table 18, and are derived from profile descriptions under forest, as done by Moormann et al. (1975). The soil series determinations are according to Smyth and Montgomery (1962).

The occurrence of these three soil groups is indicated in Table 19.

4.3. Materials and methods

The soil tillage investigations were carried out exclusively in field experiments, with most of the soil physical factors measured in the field, while the soil chemical and plant tissue analyses were done in the IITA Analytical Service Laboratory. Rice was selected as the major crop to be investigated, although on the well-drained soils maize was studied as well.

The methods used will be indicated in the paragraphs concerned. Unless otherwise stated, weed growth during the experiments was controlled as

TABLE 18. General characteristics of the three main soil groups along a typical toposequence (derived from Moormann et al., 1975).

Soil group	I. Plateau soils	II. Lower slope soils	III. Valley soils
	(Ia) with laterite gravel		
Soil series	Iwo; Egbeda; Ibadan Olorunda; Gambari (upper part)	Apomu; Iregun	Adio; Jago; Ikire; Oshun; Matako
Drainage	Well-drained	Well to moderately drained	Imperfectly to poorly drained
Texture	Medium over clayey	Uniformly sandy to loamy for at least 50 cm	Variable texture
Gravel	Presence of gravel (>2.0 mm) layers	No or little gravel at less than 50 cm	No gravels for at least 50 cm
Structure	Moderate structure	Weak, fine structure	Weak, fine structure
Pores	Common to many medium to fine pores	Many fine but few or no medium pores	Many fine pores superficially, few in subsoil, especially if poorly drained
Clay	Mainly kaolinite	Kaolinite with some 2:1 clay	Mixed kaolinite and 2:1 clay
Root growth	Gradual reduction of root growth below 15 cm	Strongly reduced root growth below 15 cm	Very strongly reduced root growth below 15 cm, especially if poorly drained

TABLE 19. Prevalence of the three main soil groups on soils derived from basement complex in West Africa (in % of total land).

Soil group	(1) IITA	(2) Western Nigeria	(3) Tropical West Africa (West of Cameroun)
I. Plateau soils	54%	38%	16–20%
II. Lower slope soils	22%	15%	8–10%
III. Valley soils	17%	14%	4–5%
Others	7%	33%	65–72% (of which 12–15% also soils on basement complex)

(1) ANON, Soil Map IITA, Soil Survey Section, M.A.N.R., Moor Plantation, Ibadan, Nigeria
(2) SMYTH and MONTGOMERY (1962)
(3) F. R. MOORMANN, personal communication (estimations)

effectively as possible by manual weeding, and fertilizer rates were equal for all treatments and all experiments, being 75 kg N, 50 kg P_2O_5 and 30 kg K_2O per ha for rice and 120 kg N, 50 kg P_2O_5 and 30 kg K_2O per ha for maize. N was applied as urea, P as single superphosphate and K as muriate of potash.

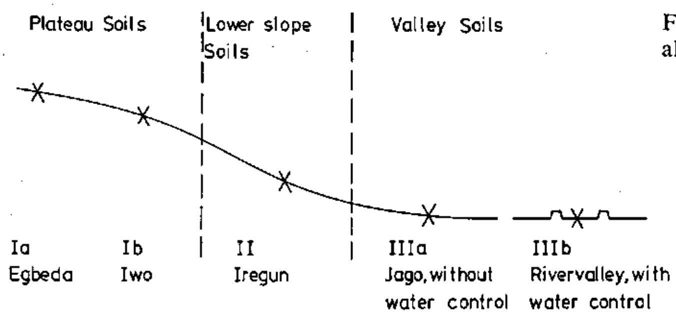


FIG. 30. Soils studied along the toposequence

The field experiments were done on the following soils (Fig. 30):

	Soil group
1. Egbeda, Plateau soil	I
2. Iwo, Plateau soil with lateritic gravel	Ia
3. Iregun, Lower slope soil	II
4. Jago, Hydromorphic soil without water control	IIIa
5. River-valley, influenced by colluvial fan material, with water control	IIIb

4.3.1. *Climatic conditions*

In Table 20, climatic data are given for Ibadan, Nigeria (7°26′N, 3°54′E), based on a 20 year period (University of Ibadan Station).

In Fig. 31, the weekly rainfall is plotted for 1974 and 1975 (March-Sept.).

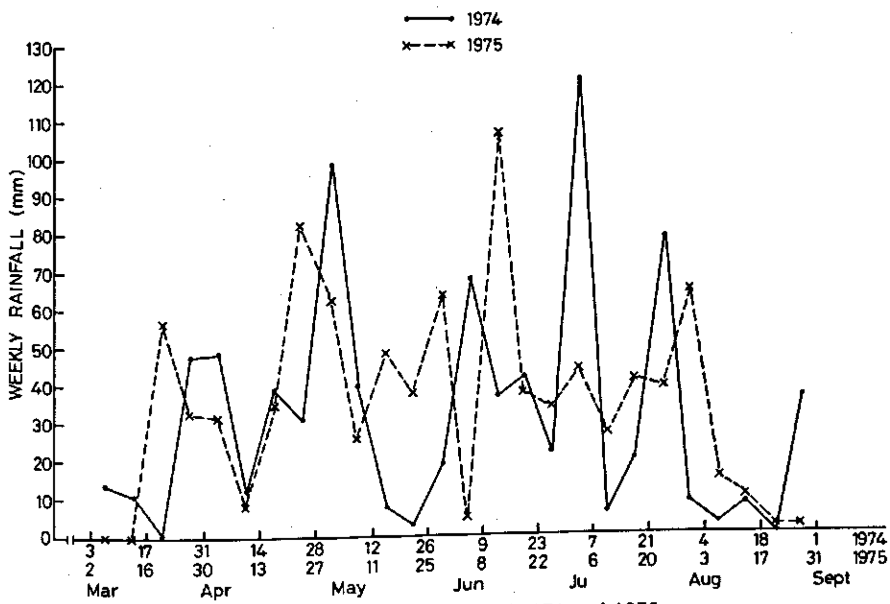


FIG. 31. Weekly rainfall data for the wet seasons of 1974 and 1975.

TABLE 20. Climatic data for Ibadan, Nigeria, based on a 20 year period (University of Ibadan Station).

	J	F	M	A	M	J	J	A	S	O	N	D
Average Maximum Temperature (°C)	32.9	34.6	33.8	32.4	31.5	29.8	28.0	27.5	28.7	30.2	32.0	32.3
Average Minimum Temperature (°C)	20.1	21.7	22.4	22.2	21.8	21.4	21.4	20.8	21.2	21.2	21.5	20.3
Average Mean Temperature (°C)	26.5	28.2	28.1	27.3	26.7	25.6	24.7	24.2	25.0	25.7	26.8	26.3
Average Relative Humidity (%)	63	61	67	74	76	80	82	83	82	78	70	64
Mean Potential Evapotranspiration (mm)	112	114	132	126	123	109	97	95	105	115	118	119
Mean Daily Possible Sunshine hours (daylength)	11.74	11.89	12.08	12.29	12.47	12.55	12.51	12.36	12.17	11.96	11.79	11.70
Mean Daily Actual Hours of Bright Sunshine	6.7	7.2	6.6	6.3	6.7	5.3	3.4	2.6	3.5	5.6	7.2	7.2
Mean Rainfall (mm)	6.3	30.2	102.7	129.3	151.0	188.1	145.5	113.3	186.3	173.4	37.1	7.7
Mean Rainfall (mm) Moor Plantation	9.4	21.1	79.5	132.5	168.1	194.1	156.7	101.1	189.0	176.0	49.5	7.1

4.4. Well-drained soils

4.4.1. *Objectives*

Although the emphasis may be somewhat different, the objectives for soil tillage on these tropical soils are in general identical to the conditions in the temperate zones: to control weeds; to incorporate plant residues, organic matter and fertilizers; to modify the soil structure, to establish land boundaries or surface configuration, thus helping to reduce erosion and levelling the soil: to break hardpans and allow better water infiltration; to prepare a good seedbed for increased germination, better root development and plant growth; to segregate foreign materials.

To indicate a desirable soil structural condition the word 'Bodengare' is used in German, 'le profil cultural' in French (Henin et al., 1969), and soil tilth in English. Kuipers (1963), in addition to these classical objectives, which are directly related to crop yield, also mentions the effect of tillage on the other agricultural practices, as a decrease in production costs has the same effect for the farmers as an increase in production. He states: 'soil tillage is as well a crop management operation as an attempt to regulate soil physical conditions. Finally it is an agricultural operation. That means that many aspects are involved and that at present the economical aim will be the final one.'

The tillage experiments on well-drained soils were carried out mainly on newly cleared soil and the main objectives of the experiments were:

- to compare tillage depths and intensities for the plateau and lower slope soils, both under conditions where crop residues were left in the field and where crop residues were removed.
- to study the potential of zero tillage practices on both soil groups
- to compare various tillage tools (on plateau soils mainly): short-handled native hand-hoe, rotary tiller, mouldboard plough, disc plough, rotavator and subsoiler.
- to study the effects of different dates of tillage.
- to study, in relation to years after clearing the forest, some selected soil physical and chemical changes for the various tillage practices.

The comparisons were made and the effects were expressed mainly in terms of crop growth and yields, weed growth (Chapter 5) and in terms of soil physical and chemical changes and differences.

4.4.2. *Literature review*

Although many different soil types exist, and in this study a distinction is made between two major soil groups on well-drained soils derived from basement complex, the following literature review covers soil tillage research on all well-drained soils without distinction. Because of the lack of necessary data on soil and climate, it was not possible to make this distinction in the literature review and it emphasizes the need for adequate soil descriptions in tillage research.

4.4.2.1. French tillage research in West Africa

In the field of upland soil tillage in West Africa, French researchers have done extensive research, mainly on the sandy to loamy soils in the sub-Sahara savannah areas with a short-duration rainy season (3–5 months). For the different kinds of crops (millet, sorghum, rice, cotton, groundnuts) they have all clearly shown the effect of land preparation on higher yields, better plant growth, better root development and lower bulk densities (CHARREAU and NICOU, 1971; NICOU and POULAIN, 1972; NICOU et al., 1970; SÉGUY, 1970; TOURTE et al., 1967). Shallow and minimum tillage techniques resulted in a substantial increase in yields over zero tillage but the best results were obtained with deep ploughing (25 cm).

After many years of research the following recommendations were made: to deep plough at the end of the rainy season, when the soil is still moist enough, and plant early next season. This is based on the fact that early planting must be done to utilize the rains for as long as possible, that deep ploughing is essential for high yields, that deep ploughing at the end of the wet season can increase the structural stability of the soil and hence is a better measure against erosion.

Most of their work has been done under conditions without crop residues and erosion is reported to be less following deep ploughing, because of higher infiltration rates (CHARREAU, 1969; KALMS, 1975), especially if done at the end of the wet season (PIERI, 1967). SÉGUY (1970) reports that following deep ploughing crops have a better resistance to droughts, because of the deeper root development and RENAUT (1974) estimates that this can be in the order of 4–5 days gained in comparison with the untilled control. SÉGUY (1970) also reports that tillage does have a residual effect during the second year if clay and organic matter content are sufficiently high.

4.4.2.2. Tillage research in East Africa

Several tillage reports have come from East Africa. Some advocate tied ridging as being better than planting on the flat (PEREIRA and BECKLEY, 1953; FAO, 1966a; MACARTNEY et al., 1971), while also reducing the risk of erosion. LAWES (1963) reports tying of alternate furrows without the use of mulch to give the same yields as the mulched treatments, with the indication, however, that this technique can only apply to areas where the rainfall is sufficiently in excess of evapotranspiration during the growing period.

WALTON (1962) indicates, that generally early planting in high yielding areas, and when water-stress is likely to occur within 8 weeks of planting, may be expected to give equal or better yields on the flat than on ridges, whilst late planting on lower-yielding areas is likely to give better results on ridges. Others report a ripping operation before the onset of the rains to increase water infiltration and to assist in root development (MACARTNEY, 1971; NORTHWOOD and MACARTNEY, 1971). HILL (1965) and BOSHOFF and HILL (1969) report preploughing cultivations, especially by rotary cultivation, to give good results and to reduce the time and cost of seedbed preparation considerably over the conventional technique where disc ploughing is the first operation. HILL (1965) also reports that after disc ploughing many subsequent operations are required before a suitable seedbed can be achieved, that mouldboard ploughing requires too high a degree of operator skill, particularly under conditions where tall vegetation and dense surface trash can be expected, and that chisel ploughs and heavy duty tillers are unable to work in heavy trash and that if the trash is removed or burnt, chisel ploughs are only effective under dry soil conditions.

Direct drilling in general has been shown to be unsuccessful, although it was indicated that direct drilling can be suitable on a young, highly fertile, Ferruginous soil (NORTHWOOD and MACARTNEY, 1971). The same authors make a plea for the concept of tilling only that strip in which the crop is planted (zonal tillage); they report that this system produces high yields and that it is a good soil and water conservation measure. They indicate that cultivation to a depth of at least 7.5 cm will be necessary and that cultivation width should not be more than 45 cm for a crop of maize planted with a row distance of 91.5 cm, in order to keep as much inter-row mulch as possible intact.

4.4.2.3. Reduced tillage techniques

Reduced tillage techniques (zero tillage, minimum tillage, mulch tillage, stubble mulching) have been receiving increasing attention over the past years. They can be of particular interest for tropical regions where rainfall intensities are high, soil physical and chemical properties decline rapidly and soils are highly erodible.

The traditional system of shifting cultivation which protects the soil well from erosion, can, however, support only 1 person on 15 ha of land (LAL, 1973b), but continuous cropping may cause total ruin to the tropical soils, more so in savannah regions (NYE and GREENLAND, 1960).

Several alternatives for shifting cultivation have been proposed to make continuous cropping possible, related to:

1. cropping practices (strip cropping, cover crops, life mulch);
2. tillage techniques (contour ploughing, ridging, reduced tillage, conservation tillage);
3. land forming activities (grading, levelling, terracing).

In this discussion the emphasis will be on the tillage techniques and especially on reduced and/or conservation tillage, which was defined by WITMUSS et al. (1973) as being synonymous with maximum or optimum retention of residues on the soil surface, as opposed to conventional tillage practices with primary and secondary tillage operations and the residues being incorporated. Several other terms are used almost synonymously to indicate reduced tillage techniques with crop residues managed on the surface: no-tillage, zero tillage, sod planting, stubble mulching, mulch tillage, till-planting, mulch farming, strip tillage.

The following are mentioned as advantages of reduced tillage techniques with crop residues on the surface: reduced water and wind erosion; higher soil moisture; higher infiltration; less changes in soil temperatures; better timing of operations and lower weather dependency; reduced labour time and equipment

FIG. 32. Mulch farming protects the soil against erosion.

FIG. 33. Small zero-tillage planter.

FIG. 34. Erosion on unprotected soil.

costs; lower energy requirements; increase in or better maintenance of organic matter; more stable soil structure; less evaporation; higher earthworm activities.

Disadvantages, on the other hand, are: unavailability of enough crop residues; reduced soil aeration; higher mechanical resistance to root penetration; more restricted nitrogen adsorption; more weed growth and more difficult weed control; inadequate planting techniques; higher requirements of management capability; unavailability of herbicides.

One of the most critical factors for these tillage techniques to be successful is the availability of crop residues on the soil surface (VAN DOREN and TRIPLETT, 1969). They report that a ploughed soil produces yields somewhere between the bare, non-tilled soil and the non-tilled soil with 100% mulch cover.

HARROLD (1972) reports soil loss to be reduced to practically zero when a surface mulch of 2–4 tons per acre was used. ANDERSON and RUSSELL (1964) state that quantities of mulch greater than 4000 lbs per acre occasionally depressed nitrate production, depressed plant height, and lengthened the growing season. BAEUMER and BAKERMANS (1973) report an amount of 3500 kg straw per ha to provide adequate soil protection from erosion without presenting problems with seeding, weed control and soil fertility. Residues mixed into the surface are less effective than those retained on the surface, but incorporation is better than removal, since incorporated residues also improve infiltration and thereby reduce run-off (WISCHMEIER, 1973). FAO (1971) reports incorporated organic material to be lost quickly through the high rate of oxidation, while it does not decompose so rapidly when left on the surface.

ANDERSON (1961) studied the surface trash conservation with different tillage tools and reported, that a wide-blade cultivator reduced the original surface cover by 15, 10 and 5% or less after the first, second and third and subsequent operations respectively, that a heavy-duty cultivator reduced the original surface cover by an average of 30–50% during primary tillage and 5–20% during the second operation, and that in general the one-way disc and the tandem disc reduced surface cover by 50% during each operation at a depth of 3 to 4 inches; surface trash reduction increased with greater tillage depth. ABEYRATNE (1962) calls for non-inversion tillage implements to leave as much crop residue on the surface as possible.

Although many researches claim that reduced tillage techniques can be applied continuously, some report that it may be necessary to do deep ploughing every few years (JENKINS, 1972; ENGEL, 1972), while MOSCHLER (1973) reports that ploughing at intervals has been slightly detrimental to yields.

Several studies have been done to investigate the plant root growth under reduced tillage techniques. LAL (personal communication) found that roots penetrate deeper following zero tillage, but noticed a slightly retarded root growth in the initial stages. The same phenomena are also reported by BAEUMER and BAKERMANS (1973). RUSSELL and SHONE (1972) argue that there are plausible grounds for considering the possibility that the soil may on occasion become a more favourable medium for root growth, if the old root and earthworm channels are not disturbed by cultivation. PHILLIPS and YOUNG (1973) report that the total root surface is not less following reduced tillage, but that the rooting patterns may be more compact or sometimes more lateral. CANNELL and FINNEY (1973) report that following direct drilling shallow root systems have usually been found for tap-rooted crops and that yields have sometimes been reduced, and that for cereals root growth has sometimes been restricted, though later growth and yield have not always been affected.

The effect of reduced tillage on nutrient uptake has also received a lot of attention. The reports indicate in general that there is a possible reduction in N-mobilization following reduced tillage and that higher rates of N may be required (VAN DER PAUW, 1963; BLEVINS et al., 1972; BAEUMER and BAKERMANS, 1973; LAL, 1975). BAEUMER and BAKERMANS (1975) report no effect on P and K, while MOSCHLER (1973) and LAL (1975) report an increase in available P in the soil following reduced tillage.

The yields obtained following reduced tillage have generally been of the same order, or slightly less, than for conventional tillage practices, depending on differences in soil, crop, climate, mulch cover, etc..

The importance of tillage-nitrogen interactions of zero tillage techniques especially should be emphasized here and will also be discussed during the interpretation of the research results in later paragraphs.

As summarized by VAN DOREN and TRIPLETT (1969) soils with different physical characteristics respond differently to no-tillage systems. It is therefore of urgent necessity to study the potential for reduced tillage techniques for different soils in the tropics, since these techniques may offer a suitable follow-up to shifting cultivation and may be the solution for continuous cropping without reducing the soil chemical and physical properties, especially since they can minimize the risk of irreparable erosion damage.

4.4.2.4. Ridging

One practice, usually being done in West Africa, especially for the major food crops, is making ridges or heaps, whereby the trash and removed weeds are deposited in the hollows and furrows. PAPADAKIS (1966) mentioned the following reasons for making ridges: to save crops during seasonal surplus of rainfall; it is one of the most efficient methods of controlling weeds; the better (surface) soil is accumulated around crop plants; the following year a mere division of the heaps or ridges into two, or their transfer, controls weeds efficiently. LAL

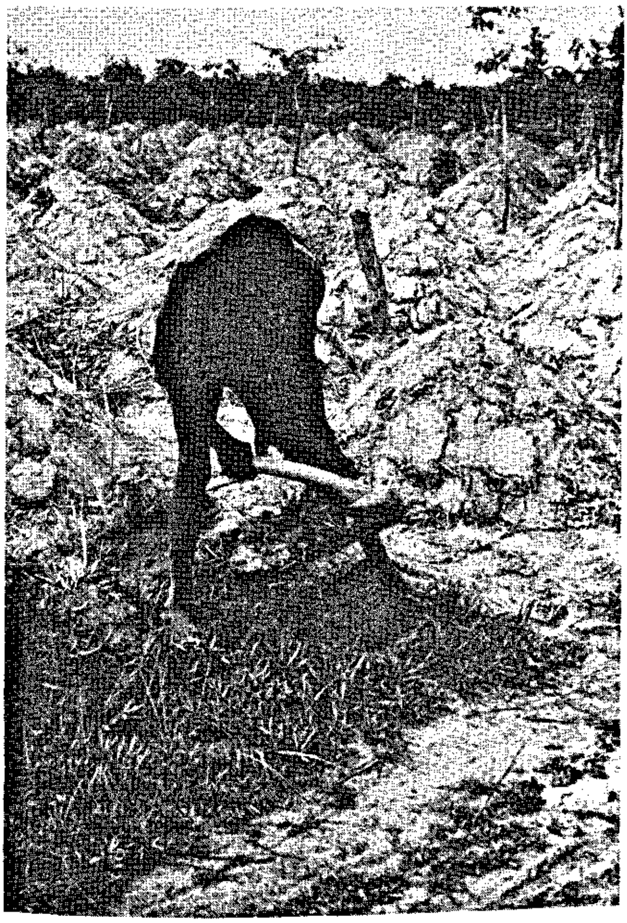


FIG. 35. Making big heaps with a hoe.

(1973a) studied different methods of seedbed preparation on well-drained soils and concluded that heaps and ridges gave the lowest yields at all planting dates, while planting on the flat or in furrows produced the highest yields. However, the experiment was kept clean and no trash was put in the hollows and furrows most susceptible to erosion.

An additional aspect of ridges may be that, if laid out properly along the contour, they can serve as an anti-erosion measure, although KOWAL and STOCKINGER (1974) indicate that the usefulness of ridging as an essential means of soil protection can be doubted. KOWAL and STOCKINGER (1974) valued ridging against the change from shifting cultivation to continuous farming. They argue that under shifting cultivation and low productivity ridging is both practical and effective; that under continuous cropping and low productivity ridges increase erosion hazards, unless laid out along the contour with graded banks and grassed waterways; that under continuous cropping and high productivity ridge cultivation is seldom justified, except to facilitate harvesting of certain crops, and that under this condition standard soil conservation measures, such as graded banks and contour rows, adequately control soil erosion.

4.4.2.5. Energy required for tillage operations

With the present discussions on energy conservation and applying low-energy input systems in agriculture, it might be useful to look into some of the energy requirements for soil tillage, since soil tillage operations will have a major effect on the power source needed. In this respect, if reduced or zero tillage conditions are feasible, this could cut down the required energy inputs.

POESSE et al. (1969) quote the following draught figures for ploughing in kgf/ dm^2:

Soil type	2 Km/HR	6 Km/HR
heavy clay	110	160
medium clay	65	85
heavy loam	55	65
light loam; heavy sand	35	45
light sand	25	35

Using these figures as a basis for calculating the power required to plough a 10 × 10 cm and a 25 × 25 cm furrow, the following results will emerge in kW (1 kW = 1.35 H.P.). (See page 77).

These figures indicate that tillage requirements, soil type and speed of operation are very important factors in assessing which power source might be desirable.

LE MOIGNE (1971) illustrated this for Senegalese conditions, where a pair of oxen, that can exert an average effort of 80–100 kg at a speed of 2.0–2.5 Km/

Soil type	2 Km/HR		6 Km/HR	
	10 × 10 cm	25 × 25 cm	10 × 10 cm	25 × 25 cm
heavy clay	6.1	38.1	26.7	166.9
medium clay	3.6	22.5	14.2	88.8
heavy loam	3.1	19.4	10.8	67.5
light loam/heavy sand	1.9	11.9	7.5	46.9
light sand	1.4	8.8	5.8	36.3

HR, can plough a wet sandy soil to a depth of 25 cm, while the same pair of oxen can only plough to a depth of 10–12 cm in a soil containing 30% clay.

4.4.3. *Plateau soils (convex)*

4.4.3.1. Introduction

Two field experiments were carried out on plateau soils; a five-year long experiment on freshly-cleared Egbeda soil, comparing ten different tillage techniques and in the later stages also studying the effects of applying crop residues, and a one season experiment on Iwo soil, comparing different tillage techniques applied at different dates, on land which had been under a crop of cowpeas after land clearing.

4.4.3.2. Field experiment on newly-cleared Egbeda soil

The site for the experiment was hand-cleared during the dry season, early 1971 and windrowed with a Caterpillar D-4 ensuring as little soil disturbance as possible.

The plots were laid out in a randomized complete block design with five replications, the main plots being 6 × 25 m.

For the first two years only rice was used as test crop, while in subsequent years both rice and maize were planted. During the first three years crop residues were removed, while during the fourth and fifth years, one half of each plot was double-mulched with a mixture of the grown rice and maize residues.

The cropping pattern for the sub-plots looked as follows:

Year	Sub-plot			
	a	b	c	d
1 (1971)	Rice	Rice	Rice	Rice
2 (1972)	Rice	Rice	Rice	Rice
3 (1973)	Maize	Rice	Rice	Maize
			Double-mulched	
4 (1974)	Maize	Rice	Rice	Maize
			Double-mulched	
5 (1975)	Rice	Maize	Maize	Rice

Ten tillage treatments were applied:

1. ZT: Zero tillage
2. HH: Hand-hoeing, with local short-handled hoe (5–8 cm)
3. RT–2: Two-wheel tractor with rotary tiller (10–15 cm)
4. PL–2: Two-wheel tractor with Japanese reversible plough (10–15 cm)
5. MPL–4S: Four-wheel tractor with mouldboard plough, shallow (13–17 cm)
6. MPL–4D: Four-wheel tractor with mouldboard plough, deep (25–30 cm)
7. DPL–4S: Four-wheel tractor with disc plough, shallow (13–17 cm)
8. DPL–4D: Four-wheel tractor with disc plough, deep (25–30 cm)
9. RoI–4: Four-wheel tractor with rotavator, intensive cultivation (20–25 cm)
10. RoSS–4: Four-wheel tractor with subsoiler and rotavator (high intensity) in year 1,2 and 3 (50 cm and 20–25 cm); no tillage in year 4 and rotavator (low intensity) (20 cm) in year 5.

4.4.3.2.1. Yields

In the first year after clearing two subtreatments on sowing were introduced, drilling versus broadcasting, and three sub-subtreatments on weed control, no weeding, hoe-weeding at 3 and 6 weeks after planting, and chemical weed control, using Preforan. Drilling and broadcasting did not show any difference and the averaged yield data are used in Table 21.

In the second year, two varieties of rice were planted, with two subtreatments on weed control, weed-free (hoe-weeding every week) and hoe-weeding at 3 and 6 weeks after planting. Due to drought stress, one variety (IR20) looked miserable at harvest and yielded only about 200 kg/ha, while the other variety (OS 6),

TABLE 21. Yields of rice (IR20) in kg/ha following ten tillage treatments on Egbeda soil. First year after clearing.

Tillage treatment	No weeding	Hoe-weeding (3 & 6 wks A.P.)	Herbicide (Preforan)
1 ZT	191	937	423
2 HH	451	1184	859
3 RT–2	378	995	776
4 Pl–2	644	1187	893
5 MPl–4S	441	1032	844
6 MPl–4D	576	1031	766
7 DPl–4S	453	958	827
8 DPl–4D	494	1202	851
9 RoI–4	491	974	929
10 RoSS–4	385	999	816
Mean	450	1051	798
Significance level	10%	n.s.	10%
LSD (.10)	308	–	432

TABLE 22. Yields of rice (OS6) in kg/ha following ten tillage treatments on Egbeda soil. Second year after clearing.

Tillage treatment	Weed-free	Hoe-weeding (3 & 6 wks A.P.)	Mean
1 ZT	1219	1039	1129
2 HH	965	1122	1044
3 RT–2	775	974	875
4 P1–2	1114	1384	1249
5 MP1–4S	1133	990	1062
6 MP1–4D	1201	1104	1153
7 DP1–4S	987	1061	1024
8 DP1–4D	1164	1178	1171
9 RoI–4	1049	1191	1120
10 RoSS–4	893	943	918
Mean	1050	1099	1074
Significance level	n.s.	n.s.	

TABLE 23. Yields of rice (IR579) and maize ($TZAC_1 \times TZBC_2$) in kg/ha following ten tillage treatments on Egbeda soil. Third year after clearing.

Tillage treatment	Rice			Maize		
	Weed-free	Hoe-weeding (3 & 6 wks. A.P.)	Mean	Weed-free	Hoe-weeding (1 & 5 wks. A.P.)	Mean
1 ZT	642	73	358	3515	3002	3259
2 HH	688	296	492	4068	3912	3990
3 RT–2	1072	145	609	3637	4051	3844
4 P1–2	1039	501	770	3730	3628	3679
5 MP1–4S	730	447	589	3712	3452	3582
6 MP1–4D	841	692	767	4296	3927	4112
7 DP1–4S	839	520	680	4012	3644	3828
8 DP1–4D	710	596	653	3675	3284	3480
9 RoI–4	642	475	559	3526	3596	3561
10 RoSS–4	771	548	660	3616	3664	3640
Mean	797	429	613	3779	3616	3698
Significance level[1]	n.s.	1%		n.s.	5%	10%
LSD (.05)	–	258		–	670	421 (LSD (.10))

[1] In all cases where the significance level is 1%, the LSD-values are given at the 5% level.

which is the recommended upland variety in Nigeria, yielded reasonably well, as indicated in Table 22.

In the third year, rice and maize were planted with two subtreatments on weed control for rice, weed-free and hoe-weeding at 3 and 6 weeks after planting, and two subtreatments on weed control for maize, weed-free and hoe-weeding at 1 and 5 weeks after planting. The yield results are presented in Table 23.

TABLE 24. Yields of rice (OS6) and maize ($TZBC_3$) in kg/ha following ten tillage treatments on Egbeda soil. Fourth year after clearing.

Tillage treatment	Rice			Maize		
	Crop residue			Crop residue		
	with	without	Mean	with	without	Mean
1 ZT	1405	1084	1245	4365	3990	4178
2 HH	1625	1520	1572	4504	4500	4502
3 RT–2	1798	1804	1801	4908	4648	4778
4 P1–2	2060	1658	1859	5068	4856	4962
5 MP1–4S	1508	1592	1550	4952	4632	4792
6 MP1–4D	1133	1093	1113	4934	4882	4908
7 DP1–4S	1464	1241	1352	4838	4717	4778
8 DP1–4D	1406	1097	1252	4949	4700	4825
9 RoI–4	1610	1262	1436	4899	4754	4827
10 RoSS–4	1585	922	1254	3922	3669	3796
Mean	1559	1327	1443	4734	4535	4635
Significance level	10%	1%		5%	1%	
LSD (.05)	524 (LSD (.10))	473		762	630	

In the fourth year, rice and maize were planted with mulching versus no mulching as subtreatments. The plots were kept weed-free. The yield data for rice and maize with and without the application of crop residue are shown in Table 24.

In the fifth year after clearing, rice and maize were again planted under the mulched an unmulched conditions and the plots were kept weed-free. The yield results are given in Table 25.

A summary of the yield data is given in Table 26.

During the first year, no significant differences were observed between tillage treatments under good weed control. With less effective weed control, however, especially zero tillage yielded lower.

During the second year, no significant differences were found between any of the treatments, possibly because of the dominant effect of drought stress.

During the third year, no significant differences were found with complete weed control. The recommended weeding practices did indicate differences; for rice deep tillage yielded highest, followed by shallow tillage, and zero tillage; for maize deep and shallow tillage yielded equally high and zero tillage less.

During the fourth year there was an effect of the mulch on zero tillage especially. Deep tillage showed less effect of the mulch, while the shallow treatments showed almost no effect. With mulch, the differences between the tillage treatments were less pronounced than without mulch. Especially no-tillage yielded lower for both rice and maize; for maize shallow tillage was equal to deep tillage, while for rice shallow tillage was better.

TABLE 25. Yields of rice (TOX 4019) and maize ($TZBC_4$) in kg/ha following ten tillage treatments on Egbeda soil. Fifth year after clearing.

Tillage treatment	Rice			Maize		
	Crop residue			Crop residue		
	with	without	Mean	with	without	Mean
1 ZT	1582	1229	1406	3975	3562	3769
2 HH	1984	1694	1839	4440	4139	4290
3 RT–2	2304	2134	2219	4793	4687	4740
4 P1–2	1979	1702	1841	4605	4461	4533
5 MP1–4S	1916	1991	1954	3972	3960	3966
6 MP1–4D	1582	1057	1320	3358	2245	2802
7 DP1–4S	1992	1491	1742	4557	4630	4594
8 DP1–4D	1859	1277	1568	3853	3452	3653
9 RoI–4	2136	1834	1985	4010	3575	3793
10 RoSS–4	2088	1632	1860	4304	3485	3895
Mean	1942	1604	1773	4186	3819	4003
Significance level	n.s.	1%		1%	1%	
LSD (.05)	–	466		718	715	

TABLE 26. Summary of yield figures, in kg/ha, under weedfree conditions, divided in zero tillage, shallow tillage and deep tillage

	Year 3		Year 4		Year 5	
	Rice	Maize	Rice	Maize	Rice	Maize
Without crop residue						
Zero tillage (Treatment 1)	642	3515	1084	3990	1229	3562
Shallow tillage (Treatments 2, 3, 4, 5, 7)	874	3832	1563	4671	1802	4375
Deep tillage (Treatments 6, 8, 9, 10)[1]	741	3778	1151	4779	1450	3189
With crop residue						
Zero tillage	–	–	1405	4365	1582	3975
Shallow tillage	–	–	1691	4854	2035	4473
Deep tillage	–	–	1383	4927	1916	3881

[1] Treatment 10 is not included in Year 4

During the fifth and final year, the same trends could be observed. The positive effect of mulch had become quite clear for zero tillage and the deep treatments, while it remained small for the shallow treatments. Under mulched conditions, the yield differences were relatively small, although the shallow treatments yielded somewhat higher. Under unmulched conditions, the yield differences were more pronounced, with especially the shallow treatments yielding significantly higher than zero tillage and the deep treatments.

4.4.3.2.2. Soil bulk density

Core samples were taken every year, at three weeks after planting in the rice plots, with a falling-weight core sampler using cores of about 210 cc.

The results for the first four years after clearing are given in Table 27 and the reported figures are the averages of 10 measurements.

In the fifth year, core samples were taken after harvesting in the rice and maize plots at three depths, 0–10 cm, 10–20 cm and 20–40 cm. The gravel contents of all samples were also determined (Table 28).

From Table 27 it appears that the bulk density has increased substantially in a period of four years. In how far this has been due to erosion and consequently to an increase in gravel content could not be determined, since these measurements were not done before starting the experiment. However, from the gravel determinations after harvesting in the fifth year, it is suggestive that an increase in gravel content might have occurred due to erosion, since the mulched plots, with better erosion protection, showed a lower percentage gravel than the unmulched plots (resp. 10.9% versus 13.8% in the 0–10 cm layer, 14.7% versus 17.0% in the 10–20 cm layer and 25.4% versus 27.5% in the 20–40 cm layer).

TABLE 27. Bulk density in g/cm^3 and pore volume in vol. % (specific density 2.67 g/cm^3) at three weeks after planting following ten tillage treatments on Egbeda soil. (Figures are the averages of 10 measurements).

Tillage treatment	Year after clearing							
	1		2		3		4	
	0–10	10–20	0–10	10–20	0–10	10–20	0–10	10–20
1 ZT	1.41	1.48	1.53	1.56	1.58	1.62	1.65	1.68
2 HH	1.35	1.49	1.49	1.61	1.58	1.64	1.64	1.68
3 RT–2	1.40	1.51	1.44	1.60	1.49	1.60	1.57	1.66
4 P1–2	1.37	1.49	1.44	1.60	1.45	1.63	1.52	1.66
5 MP1–4S	1.31	1.44	1.47	1.59	1.48	1.60	1.60	1.64
6 MP1–4D	1.37	1.43	1.40	1.49	1.53	1.54	1.53	1.54
7 DP1–4S	1.36	1.42	1.46	1.58	1.48	1.60	1.60	1.66
8 DP1–4D	1.36	1.43	1.41	1.50	1.52	1.57	1.58	1.56
9 RoI–4	1.29	1.36	1.39	1.41	1.41	1.53	1.56	1.58
10 RoSS–4	1.39	1.46	1.44	1.51	1.43	1.59	1.55	1.58
Mean	1.36	1.45	1.45	1.55	1.49	1.59	1.58	1.62
Significance level	n.s.	5%	1%	5%	1%	1%	1%	1%
LSD (.05)	–	0.085	0.069	0.109	0.062	0.058	0.063	0.040
Pore volume (%) (mean)	49.1	45.7	45.7	41.9	44.2	40.4	40.8	39.3

TABLE 28. Percentage gravel, uncorrected and corrected bulk density values after harvesting during the fifth year after clearing. (Figures are the averages of 10 measurements).

Tillage treatment	Depth (cm)	Mulching			No mulching		
		Gravel %	B.D. uncorrected	B.D. corrected[1]	Gravel %	B.D. uncorrected	B.D. corrected[1]
1 ZT	0–10	8.6	1.49	1.43	6.9	1.53	1.48
	10–20	9.9	1.57	1.51	14.0	1.57	1.47
	20–40	20.1	1.57	1.42	31.1	1.61	1.37
2 HH	0–10	9.5	1.43	1.36	12.4	1.46	1.37
	10–20	16.4	1.57	1.45	14.7	1.61	1.51
	20–40	26.8	1.60	1.40	27.1	1.66	1.46
4 P1–2	0–10	10.6	1.45	1.38	12.5	1.44	1.35
	10–20	18.8	1.54	1.40	17.4	1.52	1.39
	20–40	32.0	1.58	1.33	30.9	1.61	1.37
6 MP1–4D	0–10	14.9	1.48	1.37	23.3	1.45	1.28
	10–20	13.8	1.51	1.41	22.0	1.54	1.38
	20–40	22.8	1.53	1.36	21.0	1.52	1.37
Fallow	0–10	10.8	1.42	1.34			
	10–20	12.6	1.54	1.45			
	20–40	26.0	1.49	1.29			

[1] corrected bulk density (B.D.) $= \dfrac{\text{uncorrected B.D.} - \text{weight gravel (g/cm}^3\text{)}}{1 - \dfrac{\text{weight gravel (g/cm}^3\text{)}}{2.67\ \text{(g/cm}^3\text{)}}}$

Furthermore, the average percentage gravel in the top 40 cm shows, especially for the ploughed treatments, an increase over the fallow area (15.1% following zero tillage, 17.8% following hand-hoeing, 20.3% following shallow ploughing, 19.6% following deep ploughing versus 16.5% on the fallow area).

The data in year 5 indicate some relation between bulk density and percentage gravel, but it is unrealistic to assume that the increase in percentage gravel alone can explain the increased bulk densities over the years. Another factor responsible for this might have been the natural compaction due to exposure and raindrops, as has been suggested by several authors (CUNNINGHAM, 1963; VAN DER WEERT and LENSELINK, 1972; LAL, 1973b) or compaction due to cropping (BRADY, 1974). Also the reduction in organic matter (see Par. 4.4.3.2.8.) might have had some effect on increased compaction. This is suggested by the fact that the bulk densities following mulching are somewhat lower than following unmulched conditions.

The ploughed treatments show, especially in the 10–20 cm and 20–40 cm layers, lower bulk densities than zero tillage and hand-hoeing.

That the measured bulk densities in year 5 are lower than in year 4 may have been caused by the interference of other soil measurements taken in the plots during crop growth.

4.4.3.2.3. Root growth

During year 5, root samples were taken in the rice plots at heading and in the maize plots at tasseling, using a core sampler with cores of about 210 cc. The soil and root masses were washed and the remaining roots dried and weighed.

TABLE 29. Root weights in g/dm³ for maize at tasseling in year 5 (each figure is the average of 10 samples).

		Within the rows			Between two rows		
	Depth(cm)	0–10	10–20	20–40	0–10	10–20	20–40
Zero tillage	NM[1]	6.280	0.585	0.078	0.103	0.091	0.025
	M[2]	7.840	0.455	0.105	0.265	0.147	0.078
	Average	7.060	0.520	0.092	0.184	0.119	0.052
Shallow ploughing	NM	7.843	0.885	0.151	0.319	0.160	0.089
	M	8.941	1.283	0.222	0.221	0.219	0.044
	Average	8.392	1.084	0.187	0.270	0.190	0.067
Deep ploughing	NM	4.076	0.560	0.162	0.108	0.103	0.029
	M	5.047	0.369	0.115	0.074	0.061	0.045
	Average	4.562	0.465	0.139	0.091	0.082	0.037
Significance level:							
between tillage means		10%	5%	5%	1%	5%	n.s.
LSD (.05)		2.865 (LSD (.10))	0.445	0.075	0.127	0.067	–

[1] NM = without crop residues applied
[2] M = with crop residues applied

TABLE 30. Root weights in g/dm³ for rice at heading in year 5 (each figure is the average of 15 samples).

		Between two rows		
	Depth (cm)	0–10	10–20	20–40
Zero tillage	NM	0.350	0.103	0.039
	M	0.391	0.102	0.035
	Average	0.371	0.103	0.037
Handhoeing	NM	0.483	0.219	0.044
	M	0.821	0.226	0.040
	Average	0.652	0.223	0.042
Shallow rotary tilling	NM	0.560	0.236	0.030
	M	0.598	0.285	0.055
	Average	0.579	0.261	0.043
Shallow ploughing	NM	0.331	0.221	0.038
	M	0.529	0.365	0.065
	Average	0.430	0.293	0.052
Deep ploughing	NM	0.223	0.265	0.115
	M	0.519	0.296	0.082
	Average	0.371	0.281	0.099
Significance levels:				
between tillage means		5%	1%	1%
LSD (.05)		0.195	0.103	0.010
between mulch means		1%	10%	n.s.
LSD (.05)		0.166	0.064 (LSD (.10))	–

In maize, samples were taken close to plants within a row and in the middle between two rows, while in rice, samples were taken only in the middle between two rows. The results are presented in Tables 29 and 30; each figure is the average of 10 and 15 samples respectively.

Application of crop residues has had a positive effect on the amounts of roots for rice and maize.

For maize, deep ploughing resulted in a significantly lower root growth in the 0–10 cm layer, both vertically and laterally. Shallow tillage had a few more roots than zero tillage.

For rice, zero tillage resulted in less root growth than the shallow and deep treatments, especially in the 10–20 cm layer. Deep tillage had less roots than shallow tillage in the 0–10 cm layer, but there was no difference in the 10–20 cm layer.

4.4.3.2.4. Soil moisture

The bulk density: soil moisture relationship was determined every year, three weeks after planting. The results, as shown in Fig. 37, indicate that while no relation existed in the first year after clearing, the relation had become significant in the fourth year. This points out that the increased bulk density had a limiting influence on soil moisture, and that consequently some of the tillage treatments had resulted in a critical compaction. The same indication is given in Fig. 38, where pore volume is plotted against soil moisture for the different years.

FIG. 36. Drought stress in maize.

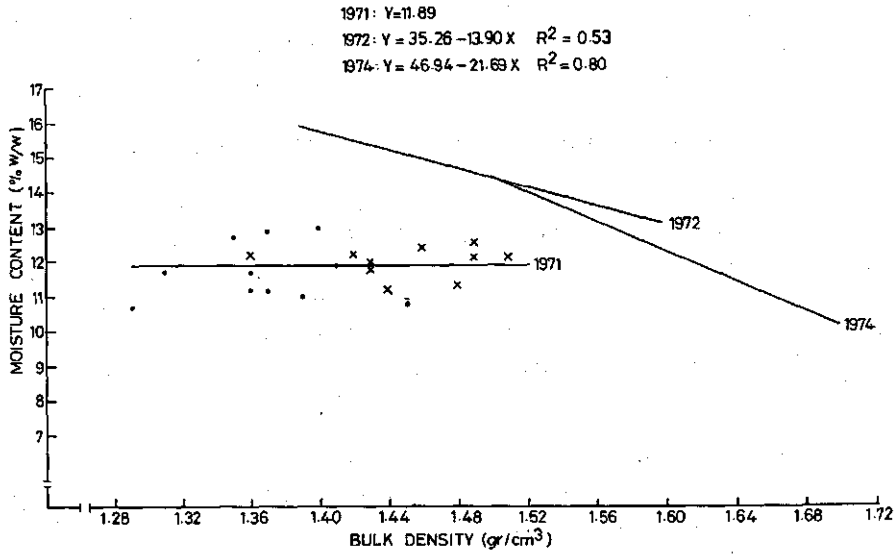


FIG. 37. Relation between soil moisture and bulk density at three weeks after planting under unmulched conditions for different years after clearing.

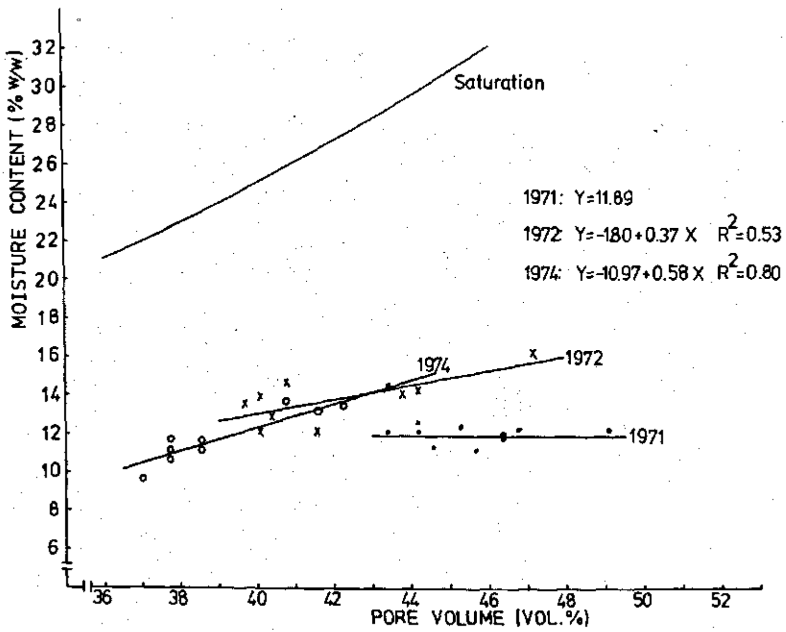


FIG. 38. Relation between pore volume and soil moisture at three weeks after planting under unmulched conditions for different years after clearing.

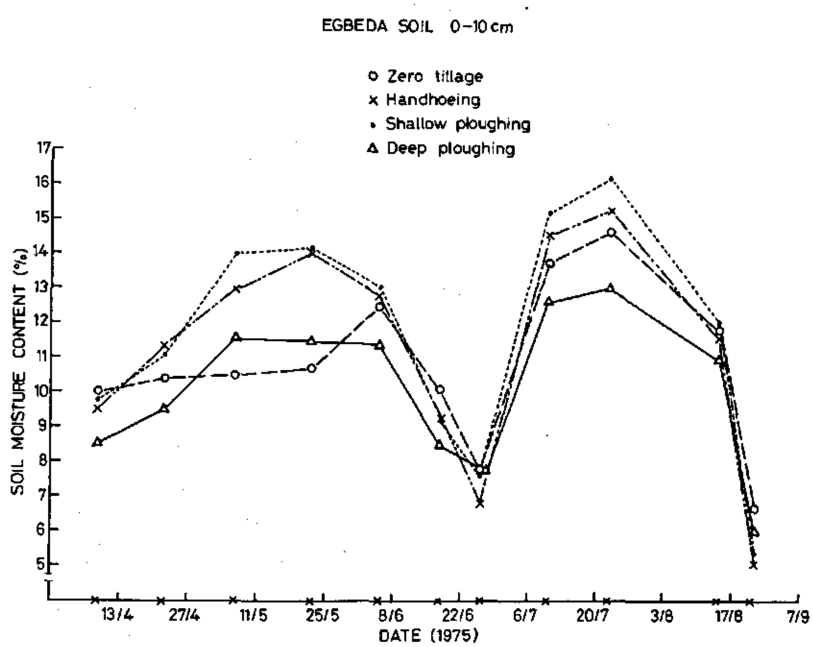


FIG. 39. Soil moisture veriations in the 0–10 cm layer during the growing season of 1975 for four tillage treatments (average of mulched and unmulched conditions).

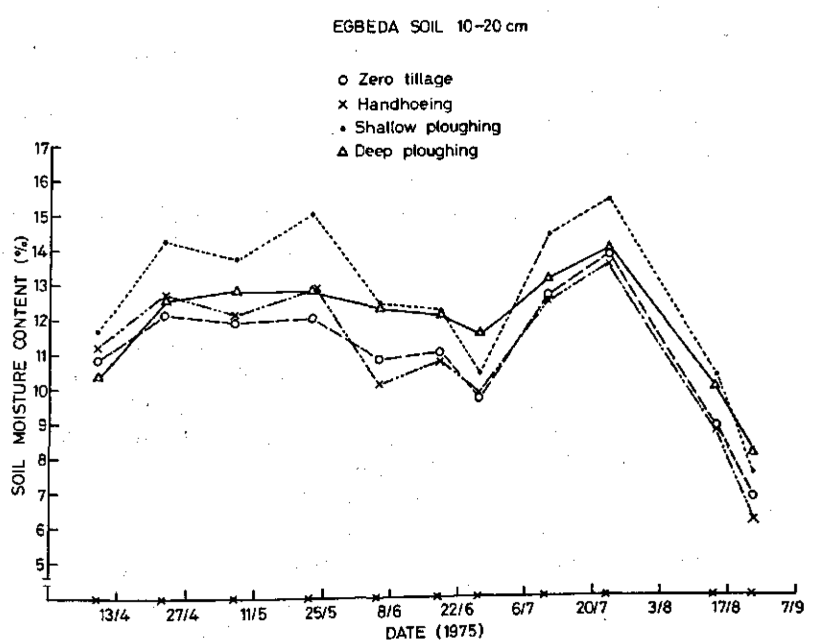


FIG. 40. Soil moisture variations in the 10–20 cm layer during the growing season of 1975 for four tillage treatments (average of mulched and unmulched conditions).

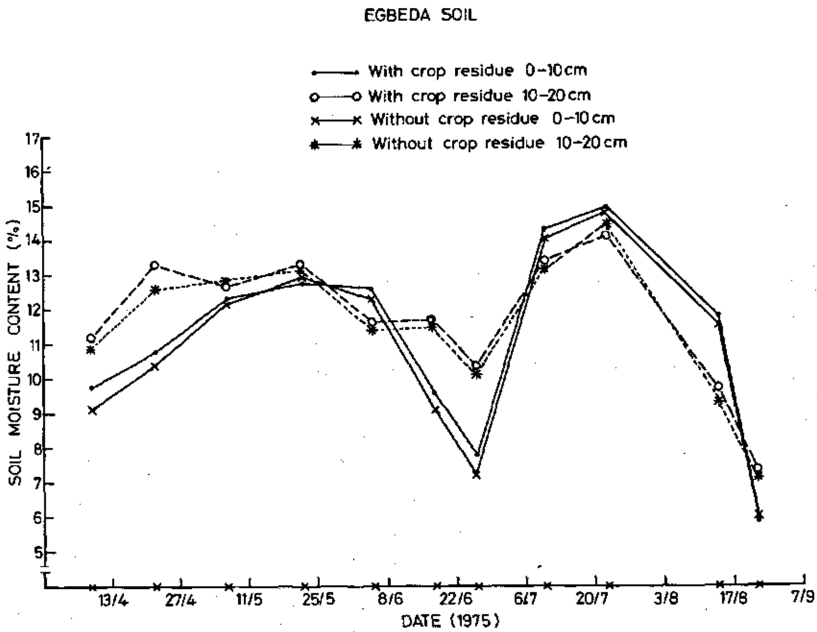


FIG. 41. Soil moisture variations in the 0–10 and the 10–20 cm layers for mulched and unmulched conditions (average of four tillage treatments).

In the fifth year, soil moisture samples were taken about every two weeks to study the soil moisture regime of different tillage treatments, with and without the application of crop residue. The results of these measurements are represented in Figs. 39 and 40.

In the 0–10 cm layer deep tillage and zero tillage have the lowest soil moisture during wet periods; in dry periods, however, especially zero tillage maintains its soil moisture at a higher level than the tilled treatments (Fig. 39) resulting in less wilting during dry periods.

In the 10–20 cm layer, zero tillage and hand-hoeing have the lowest soil moisture, regardless of wet or dry period. Shallow tillage has the highest soil moisture, although deep tillage seems to conserve water better during dry periods (Fig. 40), also resulting in less wilting during dry periods.

Mulching has some effect on soil moisture, even more so for zero tillage in the 0–10 cm layer, compared to the tilled treatments (Fig. 41).

4.4.3.2.5. Water-holding capacity (pF-values)

Measurements on water-holding capacity were made after harvesting in the fifth year, using tensiometers in the field. The results, indicated in Fig. 42, are the averages of only three measurements in the 0–10 cm layer.

The measurements taken are probably not enough to make definite conclusions. The data, however, seem to indicate that mulching increases the water-

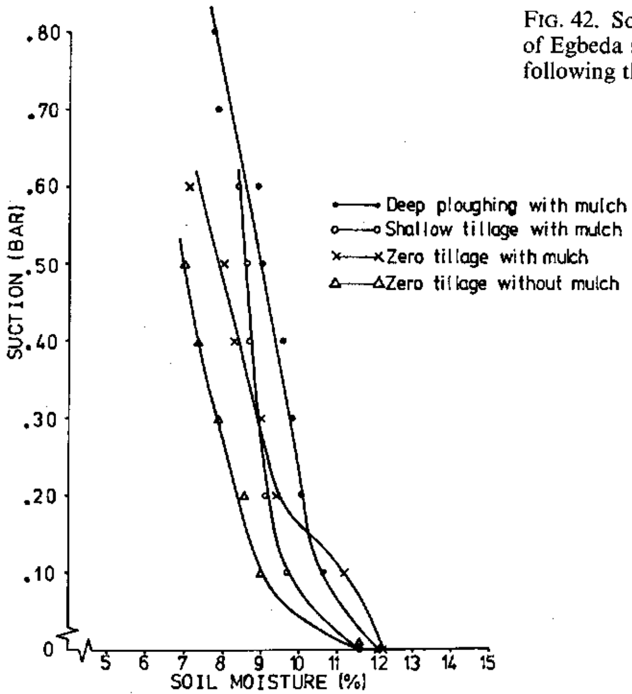


FIG. 42. Soil moisture characteristics of Egbeda soil (0–10 cm layer) following three tillage treatments.

holding capacity of the soil and that deep tillage results in a somewhat higher water-holding capacity than zero tillage.

As tensiometers were used for these measurements, the graph only indicates the values at low tension rates.

4.4.3.2.6. Plant growth

Plant height measurements were taken for rice at 10 weeks after planting in years 4 and 5, and also at harvest in year 5; plant heights in maize were measured at 5 weeks after planting in years 3, 4 and 5 (Table 31).

Mulching generally resulted in slightly taller plants in rice and maize.

Plant height was reduced by zero tillage and hand-hoeing and also by deep tillage in year 5.

Plant heights seemed to be a good indicator of the potential yields, since they correlated well.

In year 5, plant stand and lodging counts were taken for maize at harvest (Table 32). Especially after deep mouldboard ploughing were the number of plants reduced compared to most other treatments.

While in general lodging was less with mulching, zero tillage and hand-hoeing had more lodging under the mulched condition. Rotavation seemed to result in more lodging than other treatments.

Maturity of rice was delayed following deep ploughing, especially where no

TABLE 31. Plant height measurements for rice and maize in year 4 and 5 (in cm) (Average of mulched and unmulched treatments).

Tillage treatment	Rice			Maize		
	10 weeks after planting		at harvest	5 weeks after planting		
	year 4	year 5	year 5	year 3	year 4	year 5
1 ZT	83	72	118	127	106	108
2 HH	102	75	123	150	123	116
3 RT–2	105	83	137	153	137	128
4 P1–2	109	79	136	148	124	119
5 MP1–4S	108	82	135	145	120	124
6 MP1–4D	110	70	135	156	110	98
7 DP1–4S	105	81	136	149	126	125
8 DP1–4D	107	78	135	138	114	108
9 RoI–4	106	77	140	147	117	111
10 RoSS–4	90	73	127	142	96	110

TABLE 32. Plant stands and percentage lodged plants for maize in year 5 at harvest.

Tillage treatments	Plants/10 m		Lodged plants (%)	
	with mulch	without mulch	with mulch	without mulch
1 ZT	32	31	17	10
2 HH	33	36	20	10
3 RT–2	33	32	20	26
4 P1–2	32	28	7	16
5 MP1–4S	28	29	7	7
6 MP1–4D	23	16	7	11
7 DP1–4S	32	32	6	15
8 DP1–4D	28	27	8	7
9 RoI–4	30	27	14	24
10 RoSS–4	32	31	8	9
Average	30	29	11	14

crop residue was applied, by about one week over the other treatments. This accounted in year 5 to some extent for reduced yields in the deep ploughed treatments, since a drought set in shortly after heading. Harvesting of the rice in all plots was done about 30–35 days after 50% heading.

4.4.3.2.7. Infiltration rate

Infiltration rates were measured using the double-ring method, maintaining a constant water layer of about five cm within the rings. Each test was continued for three and a halve hours.

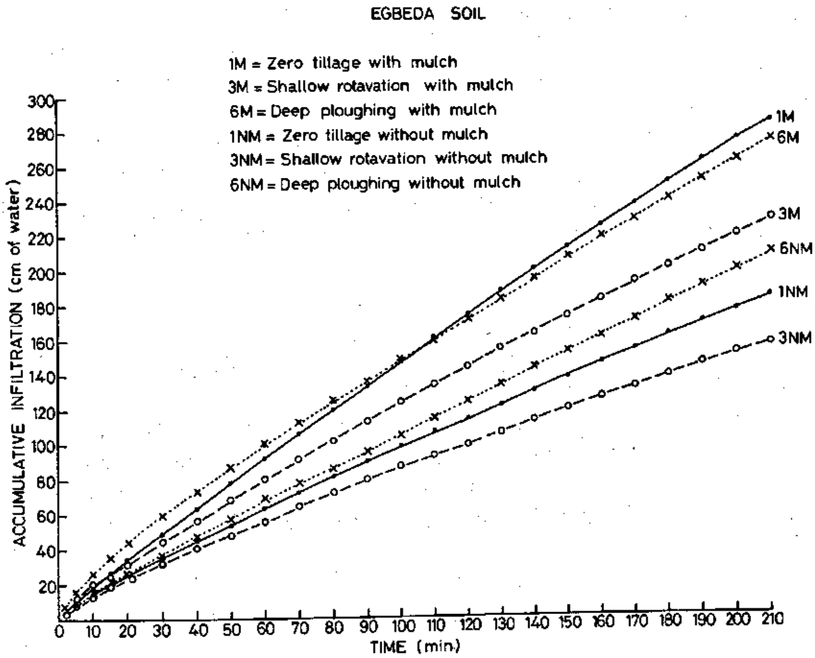


FIG. 43. Infiltration rates in Egbeda soil following three tillage treatments under mulched and unmulched conditions.

Fig. 43 gives the results of the accumulative infiltration for zero tillage, shallow tillage and deep ploughing after harvesting of the maize in year 5; the data are the averages of three measurements.

The infiltration rates, as determined by calculating the slope, are 82 cm (69) per hour for zero tillage with mulch, 82 cm (74) per hour for deep ploughing with mulch, 71 cm (56) per hour for shallow tillage with mulch, 55 cm (47) per hour for zero tillage without mulch, 54 cm (57) for deep ploughing without mulch and 48 cm (38) per hour for shallow tillage without mulch at 60 and 210 minutes resp. after starting the experiment.

TABLE 33. Soil moisture contents, one day after infiltration tests in zero tilled, shallow tilled and deep ploughed plots.

Tillage treatment	Depth (cm)			Average (0–40)
	0–10	10–20	20–40	
Zero tillage, with mulch	15.85	15.48	14.13	15.15
Deep ploughing, with mulch	14.72	14.98	15.45	15.05
Shallow tillage, with mulch	15.31	13.59	12.56	13.82
Zero tillage, without mulch	15.69	13.08	12.24	13.67
Deep ploughing, without mulch	12.95	13.63	13.93	13.50
Shallow tillage, without mulch	14.82	13.23	11.88	13.31

Mulching has clearly increased the infiltration rates of the soil.

Zero tillage with mulch and deep ploughing with mulch have the same rate, while shallow tillage with mulch has reduced the infiltration rate. The same trend is true if no crop residues are applied.

The soil moisture contents, one day after the infiltration tests, are given in Table 33; the mulched plots show a higher soil moisture than the unmulched plots and, as an average for the 0–40 cm layer, zero tillage and deep ploughing have a higher soil moisture than shallow tillage, especially under the mulched condition.

4.4.3.2.8. Soil chemical status and texture

After clearing, before planting the first crop, soil samples were taken and pH, organic carbon, and texture determined (Table 34).

After one cropping season, organic carbon (%) was determined and had decreased to 1.23% in the 0–10 cm layer and to 0.92% in the 10–20 cm layer.

In the fifth year after clearing, soil samples were taken at three weeks after planting and texture and soil chemical properties were determined (Table 35).

TABLE 34. pH, organic carbon (%) and texture immediately after clearing. (fraction smaller than 2 mm).

	Depth (cm)		
	0–10	10–20	0–20
pH (H_2O)	6.5	6.5	6.5
Organic carbon (%)	–	–	1.97
Mechanical analysis:			
% sand	65.5	67.4	66.4
% silt	14.7	15.4	15.1
% clay	19.8	17.2	18.5

TABLE 35. Texture and soil chemical analysis at three weeks after planting in year 5.

Tillage treatment	Depth (cm)	Mechanical analysis			pH (H_2O)	Organ. C (%)	CEC (me/100g)	Available P (Bray 1) (ppm)	Total N (%)
		% sand	% silt	% clay					
1. ZT	0–10	72	12	16	5.0	1.48	3.38	5.69	0.126
	10–20	68	10	22	5.4	1.03	3.03	0.32	0.093
2. HH	0–10	71	11	18	5.1	1.56	4.29	8.03	0.144
	10–20	69	9	22	5.6	1.06	3.41	0.50	0.097
4. P1–2	0–10	67	12	21	5.1	1.45	4.86	6.92	0.142
	10–20	66	10	24	5.5	1.18	3.90	1.41	0.114
6. MP1–4D	0–10	67	12	21	5.4	1.17	3.83	0.98	0.116
	10–20	68	11	21	5.3	1.21	3.39	0.63	0.108

Although definite conclusions cannot be drawn from the data, because the determinations immediately after clearing were incomplete, several changes can be indicated. The mechanical analysis shows an increase in the % sand, especially in the 0–10 cm layer, a uniform decrease in the % silt and an increase in the % clay, especially in the 10–20 cm layer. These changes may have been due to leaching of silt and clay to deeper layers and/or to erosion, through which silt and clay are washed away. These changes appear to be slightly more following zero tillage and hand-hoeing. The pH decreased considerably over the four year period and the data indicate that liming on these soils will be necessary. The % organic carbon appears to have decreased only slightly. The CEC became quite low, at least if compared with data reported by MOORMANN et al. (1975) in their description of an Egbeda profile under forest. In comparison to the data by MOORMANN et al. (1975), the available P has also decreased considerably, especially following deep ploughing, while the total N has not changed much.

Soil samples were taken again after harvesting in year 5. The data, which are the averages of 8 measurements, are presented in Table 36. The analyses indicated a decrease in pH compared to the fallow area between the plots. The

TABLE 36. Soil chemical analysis after harvesting in year 5.

Tillage treatment	Depth (cm)	pH (H_2O)	Organ. C (%)	CEC (me/100g)	Available P (Bray 1) (ppm)	Total N (%)
1 ZT	0–10	5.2	1.53	2.27	16.9	0.127
	10–20	5.5	0.86	2.48	3.0	0.089
	20–40	5.7	0.69	2.99	2.9	0.079
2 HH	0–10	5.4	1.65	3.09	15.6	0.158
	10–20	5.9	0.95	2.79	1.9	0.092
	20–40	6.0	0.61	2.88	1.2	0.085
4 Pl–2	0–10	5.4	1.64	4.03	11.6	0.166
	10–20	5.8	1.31	3.54	4.6	0.139
	20–40	6.0	0.75	3.54	2.0	0.095
6 MPl–4D	0–10	5.2	1.27	2.57	4.5	0.111
	10–20	5.7	1.12	3.14	4.2	0.101
	20–40	5.8	1.01	3.13	3.9	0.109
With crop residue (average)	0–10	5.3	1.51	3.02	11.7	0.144
	10–20	5.7	1.02	2.73	3.1	0.098
	20–40	5.9	0.74	3.06	2.2	0.087
Without crop residue (average)	0–10	5.4	1.53	2.96	12.6	0.137
	10–20	5.9	1.10	3.25	3.7	0.113
	20–40	5.9	0.78	3.21	2.8	0.097
Fallow	0–10	6.1	1.83	3.29	4.7	0.155
	10–20	6.2	0.91	3.49	1.1	0.097
	20–40	6.3	0.71	3.15	2.0	0.083

application of crop residues did not appear to have had major effects on soil chemical properties compared to the removal of crop residues. Deep ploughing resulted in less available P in the 0–10 cm layer, while the organic carbon and the total N were also slightly lower in the 0–10 cm layer than following the other tillage treatments.

4.4.3.2.9. Plant tissue analysis

In years 4 and 5, plant leaf samples were collected at the flowering stage, dried, ground and analysed (Tables 37 and 38). No differences were found in nutrient uptake for rice and maize, except for total N which indicated an upward trend with intensified tillage. The Fe content was around the critical level and the total N was also at about the deficiency level, making the plants look yellowish in the field.

TABLE 37. Plant tissue analysis of rice at flowering stage in years 4 and 5 (Average values of mulched and unmulched treatments).

Tillage treatment	Total N %	Total P %	K %	Ca %	Mg %	Mn ppm	Fe ppm	Zn ppm
				1974 (year 4)				
1 ZT	3.02	0.23	1.90	0.33	0.25	795	84	24
2 HH	3.04	0.22	1.91	0.39	0.27	774	96	23
4 P1–2	3.06	0.20	1.89	0.40	0.25	700	76	23
6 MP1–4D	3.10	0.20	2.00	0.36	0.22	493	68	22
				1975 (year 5)				
1 ZT	2.85	0.23	1.55	0.43	0.19	618	70	26
2 HH	2.91	0.22	1.63	0.43	0.19	644	92	32
3/4 RT–2/P1–2	3.00	0.21	1.64	0.53	0.20	613	86	29
6/8 MP1–4D/DP1–4D	3.22	0.20	1.73	0.47	0.19	461	89	28
				1975 (year 5)				
With crop residue	3.00	0.22	1.65	0.46	0.19	588	83	28
Without crop residue	3.07	0.21	1.65	0.49	0.20	548	87	29

TABLE 38. Plant tissue analysis for maize at flowering stage in year 5 (Average values of mulched and unmulched treatments).

Tillage treatment	Total N %	Total P %	K %	Ca %	Mg %	Mn ppm	Fe ppm	Zn ppm
1 ZT	2.24	0.24	2.22	0.44	0.20	74	258	43
2 HH	2.34	0.25	2.29	0.43	0.22	87	264	43
4 P1–2	2.40	0.25	2.34	0.45	0.23	80	294	45
6 MP1–4D	2.41	0.27	2.50	0.46	0.24	66	294	48
With crop residue	2.37	0.25	2.28	0.44	0.23	78	272	43
Without crop residue	2.32	0.25	2.40	0.45	0.21	76	283	46

4.4.3.3. Field experiment on Iwo soil

This plateau soil was slightly gravelly in the top 10 cm, but below this the gravel was more abundant and lateritic.

After hand-clearing the land and after discing and shallow ridging, one crop of cowpeas was grown at the beginning of the wet season 1972.

A tillage experiment was performed with six tillage treatments, applied at four different dates, while zero tillage was used as control. The four tillage dates were: (T_1) the end of the wet season (Nov. 1972), (T_2) the end of the dry season (March, 1973), (T_3) the beginning of the wet season (April, 1973) and (T_4) just before planting (beginning of June, 1973).

No additional mulching to the cowpea residues (very few) was done; rice was used as test crop.

Bulk density was measured at three weeks after planting at two depths and the results, which are the averages of 8 measurements, are given in Table 39. The results seem to indicate that the resulting bulk density in the 10–20 cm layer is higher as the soil moisture content at the time of tillage increases. The yields did not indicate a difference between the tillage dates (2308 kg/ha for T_1; 2449 kg/ha for T_2; 2425 kg/ha for T_3 and 2251 kg/ha for T_4) and the average values for the four tillage dates are presented in Table 40.

TABLE 39. Bulk density in g/cm³ following two tillage treatments and four tillage dates on Iwo soil.

Tillage treatment	Depth (cm)	Date of tillage				
		end wet season	end dry season	beginning wet season	before seeding	Mean
Disc ploughing	0–10	1.50	1.52	1.49	1.51	1.51
(15 cm)	10–20	1.62	1.60	1.65	1.69	1.64
Disc ploughing	0–10	1.54	1.58	1.59	1.57	1.57
(25 cm)	10–20	1.59	1.60	1.63	1.65	1.62
Mean	0–10	1.52	1.55	1.54	1.54	1.54
	10–20	1.61	1.60	1.64	1.67	1.63

TABLE 40. Yields of rice (IR528) in kg/ha following seven tillage treatments on Iwo soil.

Tillage treatment	Yields in kg/ha
Handhoeing (5–8 cm)	2016
Disc ploughing (15 cm)	2284
Disc ploughing (25 cm)	2419
Mouldboard ploughing (15 cm)	2509
Rotavation (15 cm)	2406
Tine cultivation (15 cm)	2515
Zero tillage	1679
Significance level	1%
LSD (.05)	385 kg/ha

Most tillage treatments yielded the same, but zero tillage and hand-hoeing had significantly lower yields.

4.4.4. *Lower slope soils (concave)*

4.4.4.1. Introduction

The lower slope soils in the concave part of a toposequence form little less than half the area of the plateau soils (Table 19). The soil series occurring are mainly Apomu and Iregun. These lower slope soils are different from the plateau soils, in that gravel layers are not present or are only of minor importance for at least 50 cm and that the texture is uniformly sandy to loamy for at least 50 cm, as opposed to plateau soils which do have gravel layers and become more clayey with depth.

It appears that the structure is weaker, the pores are finer and the root growth below 15 cm is more reduced than with plateau soils (MOORMANN et al., 1975 and Table 18).

4.4.4.2. Field experiment on Iregun soil

A two-year tillage experiment was conducted on Iregun soil with rice and maize as crops on land which had had only one crop of maize after clearing. The experiment had a randomized complete block design with four replications.

The objective of the experiment was threefold:

1. To study the effect of different tillage intensities on growth and yield. The following were applied as tillage practices: zero tillage, shallow rotavation (6–9 cm) and ploughing (20 cm).
2. To study the effect of application of crop residue. In half the plots, the crop residue was removed and on the other half a mixture of the removed rice and maize residues was applied in addition to the already present residues.
3. To study the effect of different dates of tillage. Two tillage dates were studied, T_1 at the end of the wet season and T_2 at the beginning of the wet season before planting.

This resulted in twelve treatments as follows:

1.	PT_1	Ploughing, T_1, without crop residue
2.	PT_2	Ploughing, T_2, without crop residue
3.	PT_1Ri	Ploughing, T_1, with crop residue ploughed-in
4.	PT_2Ri	Ploughing, T_2, with crop residue ploughed-in
5.	PT_1Ro	Ploughing, T_1, with crop residue applied after ploughing
6.	PT_2Ro	Ploughing, T_2, with crop residue applied after ploughing
7.	ST_1	Shallow rotavation, T_1, without crop residue
8.	ST_2	Shallow rotavation, T_2, without crop residue
9.	ST_1Ri	Shallow rotavation, T_1, with crop residue incorporated
10.	ST_2Ri	Shallow rotavation, T_2, with crop residue incorporated
11.	ZT	Zero tillage, without crop residue
12.	ZTR	Zero tillage, with crop residue.

4.4.4.2.1. Yields

The yields for rice and maize are given in Tables 41 and 42. Very significant yield differences resulted from the applied treatments in this soil type. These differences were mainly due to tillage, with the deepest and most intensive tillage yielding significantly higher than shallow and zero tillage. Shallow tillage yielded somewhere in between ploughing and zero tillage. Application of crop residue had no effect on the rice yields and only little effect on the maize yields; this may have been partly due to the residue decomposition and to

TABLE 41. Yields of rice and maize in kg/ha following two dates of tillage and three tillage practices, with and without crop residue left, on Iregun soil.

Tillage treatment	Second year after clearing		Third year after clearing	
	Rice (IR579)	Maize ($TZBC_3$)	Rice (TOX4019)	Maize ($TZBC_4$)
1 PT_1	1757	4928	2116	3854
2 PT_2	1435	5054	1902	4183
3 PT_1Ri	1783	5270	2239	4206
4 PT_2Ri	1378	5114	2232	4337
5 PT_1Ro	1386	5387	1878	3665
6 PT_2Ro	1428	5389	1915	4388
7 ST_1	791	4473	1798	3378
8 ST_2	864	4370	1653	3295
9 ST_1Ri	727	4839	1678	3450
10 ST_2Ri	1104	5004	1633	4215
11 ZT	379	3784	1040	2723
12 ZTR	530	3618	1023	3448
Significance level	1%	1%	1%	1%
LSD (.05)	613	454	438	771

TABLE 42. Yields of rice and maize in kg/ha with the main treatments pooled together.

Pooled treatments	Treatment Number	Year 2		Year 3	
		Rice	Maize	Rice	Maize
T_1	1, 3, 5, 7, 9	1289	4979	1942	3711
T_2	2, 4, 6, 8, 10	1242	4986	1867	4084
With crop residue	3, 4, 9, 10	1248	5057	1946	4052
Without crop residue	1, 2, 7, 8	1212	4706	1867	3678
Ploughing	1, 2, 3, 4, 5, 6	1528	5190	2047	4106
Shallow Rotavation	7, 8, 9, 10	872	4672	1691	3585
Zero tillage	11, 12	455	3701	1032	3086

TABLE 43. Bulk density in g/cm^3 and pore volume in vol. % (specific density 2.64 g/cm^3) at three weeks after planting and after harvesting, following two dates of tillage and three tillage practices, in year 3 on Iregun soil.

Tillage treatment	Three weeks after planting				After harvesting					
	0–10 cm		10–20 cm		0–10 cm		10–20 cm		20–30 cm	
	g/cm^3	vol. %	g/cm^3	vol. %	g/cm^3	vol. %	g/cm^3	vol. %	g/cm^3	vol. %
1 PT_1	1.49	43.6	1.57	40.5						
2 PT_2	1.46	44.7	1.56	40.9						
3 PT_1Ri	1.51	42.8	1.58	40.2						
4 PT_2Ri	1.51	42.8	1.54	41.7	1.51	42.8	1.45	45.1	1.61	39.0
5 PT_1Ro	1.48	43.9	1.63	38.3						
6 PT_2Ro	1.51	42.8	1.60	39.4						
7 ST_1	1.54	41.7	1.66	37.1						
8 ST_2	1.54	41.7	1.68	36.4						
9 ST_1Ri	1.53	42.0	1.65	37.5						
10 ST_2Ri	1.52	42.4	1.66	37.1	1.47	44.3	1.59	39.8	1.61	39.0
11 ZT	1.59	39.8	1.67	36.7						
12 ZTR	1.53	42.0	1.67	36.7	1.52	42.4	1.59	39.8	1.62	38.6
Ploughing	1.49	43.6	1.58	40.2						
Superficial rotavation	1.53	42.0	1.66	37.1						
Zero tillage	1.56	40.9	1.67	36.7						

earthworms, termites, etc., or to other limiting factors such as, for example, high compaction.

The different dates of tillage also showed no differences in the rice yields and only small differences in the yields of maize in year 3, with T_2 being higher than T_1. This may be explained by the so-called 'Birch-effect', which means that, when a dry soil is moistened, an enhanced decomposition of organic matter occurs (BIRCH, 1958; RUSSELL, 1973). Since in the T_1-treatments the crop residues are mixed in the soil during the dry season, they may become decomposed more quickly when the rains start than when not mixed in the soil during the dry season and at the beginning of the rains.

4.4.4.2.2. Soil bulk density

The gravel content in the soil was low and uniform for all treatments, being about 2.9% in the 0–10 cm, 3.2% in the 10–20 cm and 3.5% in the 20–30 cm layer.

Bulk density was measured three weeks after planting and after harvesting in year 3; the data in Table 43 are the averages of 8 measurements. Soil tillage does have a clear effect on reduced bulk density, the more so if deeper. Especially the 10–20 cm layer showed substantial differences. Mulching in the zero tilled plots seems to lower the bulk densities in the 0–10 cm layer compared to no mulching. The measured bulk density values are somewhat lower after harvesting than at three weeks after planting. This may have been caused by the interference of other soil measurements taken in the plots during crop growth. The trend in differences in both measurements, however, is the same.

4.4.4.2.3. Root growth

Root samples were collected at flowering time in year 3 for rice and maize.

The data in gr. dry weight/dm^3 are presented in Tables 44 and 45 and are the averages of 8 samples. Root growth following ploughing was much better than

TABLE 44. Root weights in g/cm^3 for maize at tasseling in year 3 (each figure is the average of 8 samples).

		Within the rows			Between the rows		
		0–10 cm	10–20 cm	20–40 cm	0–10 cm	10–20 cm	20–40 cm
Ploughing	NM	4.614	0.651	0.102	0.258	0.165	0.065
	M	4.258	0.577	0.160	0.177	0.113	0.054
	Average	4.436	0.614	0.131	0.218	0.139	0.060
Shallow rotavation	NM	1.656	0.226	0.107	0.125	0.155	0.051
	M	2.995	0.639	0.115	0.130	0.115	0.022
	Average	2.326	0.433	0.111	0.128	0.135	0.037
Zero tillage	NM	2.880	0.410	0.138	0.133	0.125	0.045
	M	2.799	0.246	0.109	0.162	0.113	0.065
	Average	2.840	0.328	0.124	0.148	0.119	0.055

TABLE 45. Root weights in g/dm³ for rice at heading in year 3 (each figure is the average of 8 samples).

		Between two rows		
		0–10 cm	10–20 cm	20–40 cm
Ploughing	NM	0.285	0.162	0.033
	M	0.274	0.156	0.044
	Average	0.280	0.159	0.039
Shallow rotavation	NM	0.262	0.088	0.008
	M	0.256	0.085	0.019
	Average	0.259	0.087	0.014
Zero tillage	NM	0.177	0.069	0.007
	M	0.146	0.062	0.012
	Average	0.162	0.066	0.010

following shallow and zero tillage, indicating that compaction was prohibitive to root development for zero and shallow tillage. The effect, if any, of mulch on root growth in this soil was not clear.

4.4.4.2.4. Soil moisture

Soil moisture samples were taken every month from November 1974 till April 1975 on the T_1-tilled and the zero tillage plots to study the soil moisture regime during the dry season (Fig. 44). The drying out of the zero and shallow

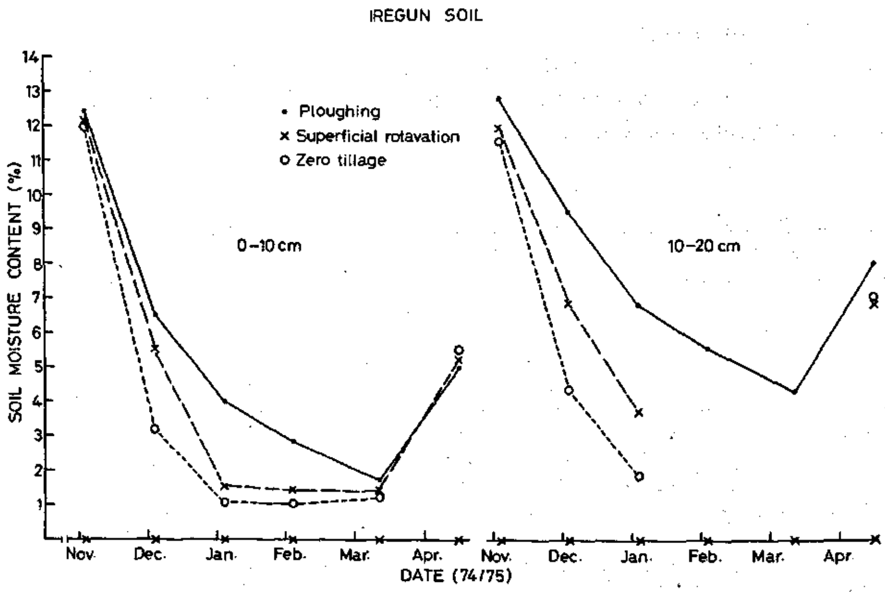


FIG. 44. Soil moisture variations in the 0–10 and 10–20 cm layers during the dry season following three tillage practices.

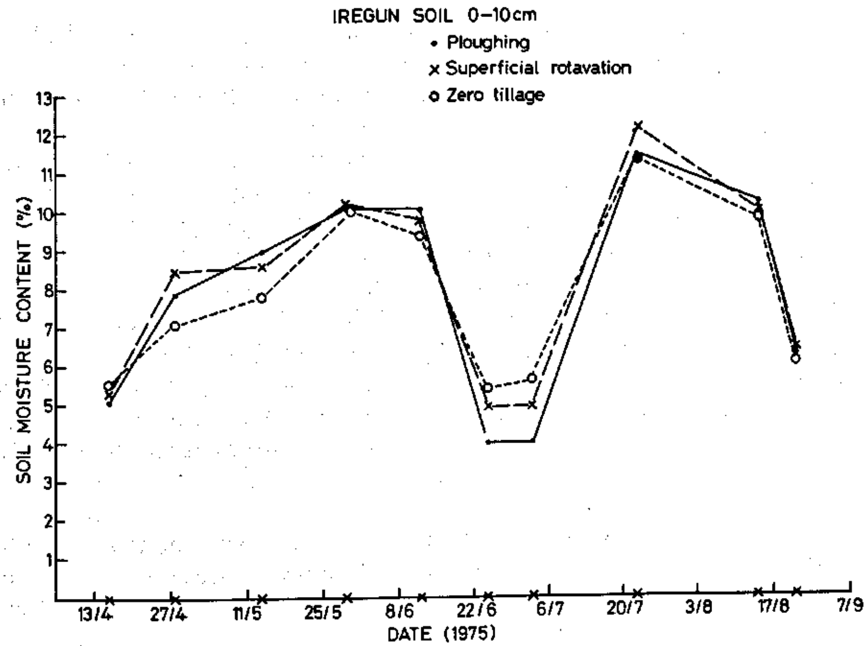


FIG. 45. Soil moisture variations in the 0–10 cm layer during the growing season of 1975 for three tillage treatments (average of mulched and unmulched conditions).

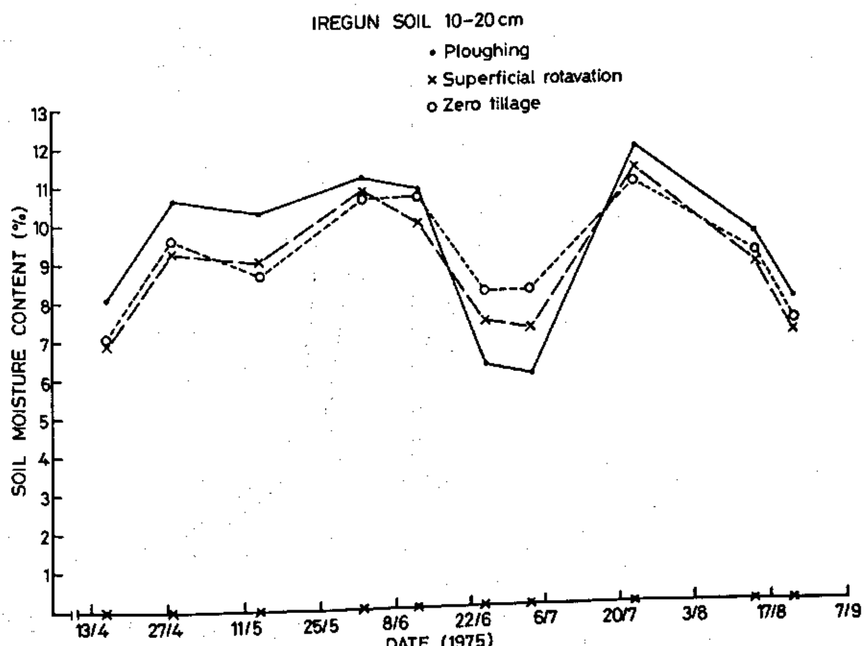


FIG. 46. Soil moisture variations in the 10–20 cm layer during the growing season of 1975 for three tillage treatments (average of mulched and unmulched conditions).

tilled plots appears to be much more rapid than that of the ploughed plots. After planting soil moisture samples were taken about every two weeks in all plots and the averaged results for the different dates of tillage and the different mulching practices are presented in Figs. 45 and 46.

Mulching showed only a slight increase in soil moisture in the 0–10 cm layer following zero and shallow tillage and in the 10–20 cm layer following ploughing. Tillage at the beginning of the wet season (T_2) also showed a slight increase in soil moisture over tillage at the end of the wet season (T_1).

During wet periods, ploughing showed a higher soil moisture, especially in the 10–20 cm layer. In dry periods, zero and shallow tillage indicated a higher soil moisture than ploughing. These results, if combined with Fig. 44, lead us to think that this is most probably due to the fact that, because of the smaller plants, the evaporation from plants in the zero and shallow tilled plots is less than in the ploughed plots, resulting in a higher soil moisture during dry periods.

4.4.4.2.5. pF-values

Measurements on the water retention characteristics were done in the field after the final harvesting, using tensiometers. The results are shown in Fig. 47 and are the averages of three measurements in the 0–10 cm and 10–20 cm layers.

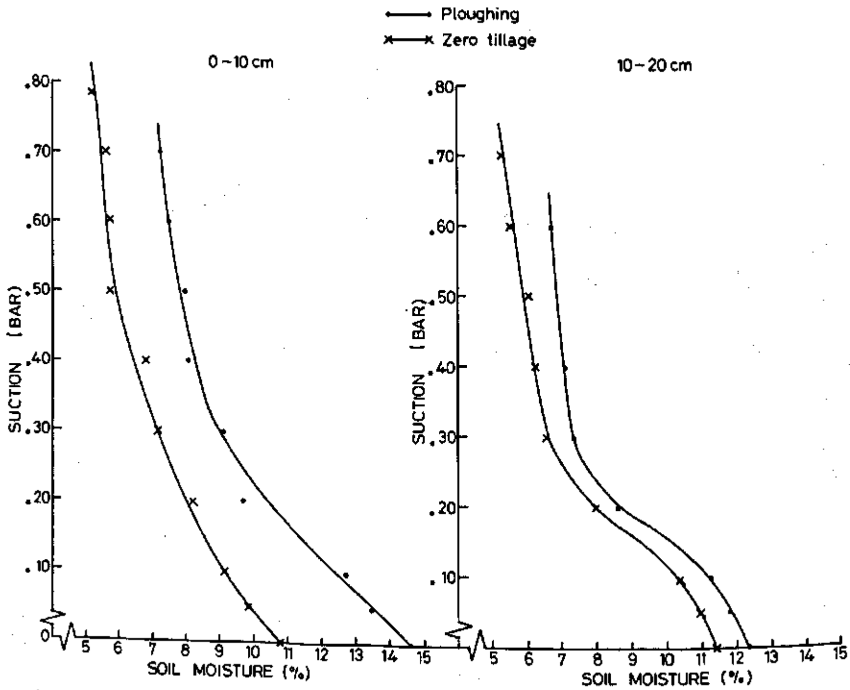


FIG. 47. Soil moisture characteristics of Iregun soil (0–10 cm and 10–20 cm layers) following two tillage treatments.

The figures indicate that the ploughed soil has a higher water-holding capacity than the zero tilled soil for the measured suctions. They also show that in dry periods wilting is more likely to occur in zero tilled soil, if plant growth and root development are equal to the ploughed soil.

The conclusion made in Par. 4.4.4.2.4., that the higher soil moisture contents measured in the zero tilled plots during dry periods are due to the fact that water substraction from the soil is less, because of less plant and root development, seems therefore justified.

4.4.4.2.6. Plant growth

Plant height measurements in rice and maize were made each year and the results are presented in Table 46. Intensified tillage on this soil increases plant height significantly for rice and for maize. Mulching has no effect on plant height after ploughing, but it does after shallow tillage, notably when done at the beginning of the wet season, and zero tillage.

Germination was no different for the various treatments, resulting in 30 to 35 plants per 10 m. Lodging was also the same for all treatments, about 3–6%.

4.4.4.2.7. Infiltration rate

Infiltration was measured after harvesting the last crop of maize, using the

TABLE 46. Plant height measurements for rice and maize following two dates of tillage, three tillage practices, with and without crop residue left, on Iregun soil.

Tillage treatment	Year after clearing				
	2		3		
	Rice (8 weeks A.P.)	Maize (5 weeks A.P.)	Rice		Maize (5 weeks A.P.)
			(8 weeks A.P.)	(at harvest)	
1 PT_1	71	165	78	105	139
2 PT_2	71	174	80	99	143
3 PT_1Ri	75	167	84	102	148
4 PT_2Ri	69	161	83	101	158
5 PT_1Ro	66	163	74	94	125
6 PT_2Ro	68	170	83	96	140
7 ST_1	61	143	67	93	111
8 ST_2	63	153	66	93	116
9 ST_1Ri	57	151	61	90	102
10 ST_2Ri	69	162	61	100	130
11 ZT	57	133	54	84	93
12 ZTR	57	149	54	88	109
Ploughing	70	167	80	100	142
Superficial rotavation	63	152	64	94	115
Zero tillage	57	141	54	86	101

double-ring method. The results are given in Fig. 48, and are the averages of three measurements.

Ploughing did increase the infiltration rate of the soil substantially, compared to shallow and zero tillage. Mulch effects on infiltration could not be detected.

The soil moisture data of one day after the infiltration tests are given in Table 47. Ploughing shows a slightly higher soil moisture than shallow and zero tillage, especially in the deeper layers.

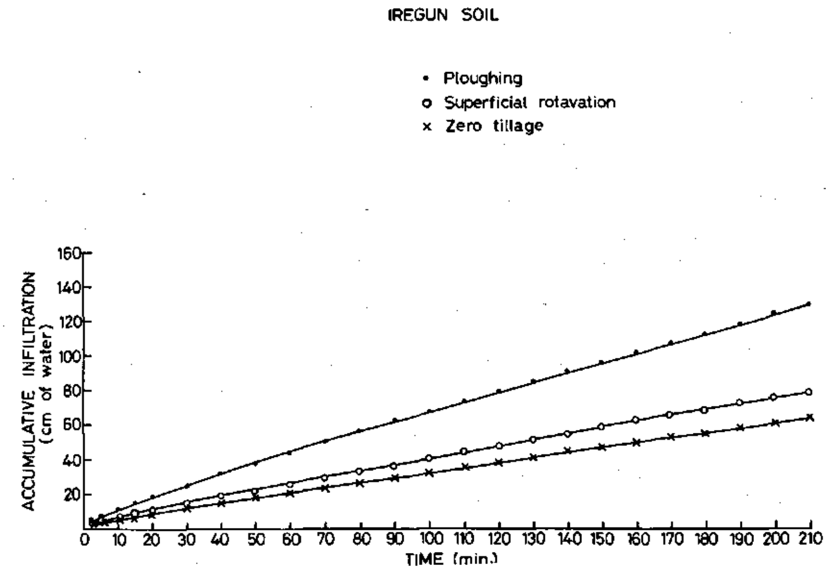


FIG. 48. Infiltration rates in Iregun soil following three tillage methods (average of mulched and unmulched conditions).

TABLE 47. Soil moisture contents, one day after infiltration measurements (Iregun Soil).

Tillage treatment	Depth			Average (0–30 cm)
	0–10 cm	10–20 cm	20–30 cm	
Ploughing	14.12	13.62	12.67	13.47
Superficial rotavation	15.15	12.95	11.57	13.22
Zero tillage	14.08	12.36	11.24	12.56

4.4.4.2.8. Soil chemical status and texture

Soil texture and chemical characteristics were determined from soil samples collected at three weeks after planting in year 3 (Table 48).

Not many conclusions can be drawn from these data. In comparison to the data reported on an Iregun profile under forest by MOORMANN et al. (1975), the pH has decreased from an original value of about 6.5 and the available P has been reduced, while for the other values no major differences were found. This Iregun soil has a sandy loam texture and is more sandy than the Egbeda soil.

TABLE 48. Texture and soil chemical analysis at three weeks after planting in year 3.

Tillage treatment	Depth (cm)	Mechanical analysis			pH (H_2O)	Organ. C (%)	CEC (me/ 100 g)	Available P (Bray 1) (ppm)	Total N (%)
		% sand	% silt	% clay					
Ploughing	0–10	78	9	13	5.5	1.21	2.78	11.16	0.138
	10–20	77	10	13	5.7	0.95	2.82	6.44	0.113
Superficial	0–10	78	10	12	5.7	1.30	3.20	11.84	0.141
rotavation	10–20	79	9	12	5.9	0.88	2.49	6.73	0.074
Zero tillage	0–10	79	10	11	5.7	1.10	2.79	9.18	0.116
	10–20	79	9	12	5.8	0.67	2.04	3.19	0.096

TABLE 49. Soil chemical analysis after harvesting in year 3.

Tillage treatment	Depth (cm)	pH (H_2O)	Organ. C %	CEC (me/100 g)	Available P (Bray 1) (ppm)	Total N (%)
Ploughing	0–10	5.6	1.43	2.16	6.6	0.108
	10–20	5.9	1.46	2.53	5.9	0.099
	20–30	6.1	0.91	1.91	1.5	0.053
Superficial	0–10	5.6	1.50	2.69	15.9	0.105
rotavation	10–20	6.1	1.24	1.56	3.4	0.075
	20–30	6.2	0.89	1.97	1.5	0.058
Zero tillage	0–10	5.7	1.63	2.31	15.5	0.124
	10–20	5.9	1.33	2.29	4.3	0.086
	20–30	6.1	1.00	2.31	2.3	0.067

Soil samples were collected again after harvesting in year 3 and the results of the analyses, which are the averages of 8 measurements, are given in Table 49. The results did not seem to indicate major differences between the tillage treatments. Compared to the analyses done at three weeks after planting, the organic carbon appeared to have increased slightly, while the CEC-values appeared to have decreased.

4.4.4.2.9. Plant tissue analysis

Plant leaves were collected, dried and ground in year 3 at flowering time for rice and maize. The tissue analyses are given in Tables 50 and 51.

No differences in nutrient uptake for the various tillage and mulching treatments were found. Nitrogen deficiency appears to be a problem in this soil.

4.4.5. *Discussion*

Soil tillage requirements differ for different soils. For the well-drained soils on basement complex two groups of soils can be differentiated: the plateau soils and the lower slope soils. The major differences between the groups are: (a)

TABLE 50. Plant tissue analysis of rice leaves, collected at flowering time in year 3 (Iregun Soil).

Tillage treatment	Total N %	Total P %	K %	Ca %	Mg %	Mn ppm	Fe ppm	Zn ppm
Ploughing	2.31	0.20	3.38	0.56	0.40	456	449	42
Superficial rotavation	2.29	0.22	3.41	0.50	0.38	439	489	39
Zero tillage	2.54	0.25	3.49	0.49	0.40	438	463	46

TABLE 51. Plant tissue analysis of maize leaves, collected at flowering time in year 3 (Iregun Soil).

Tillage treatment	Total N %	Total P %	K %	Ca %	Mg %	Mn ppm	Fe ppm	Zn ppm
Ploughing	2.52	0.28	2.01	0.31	0.25	90	195	28
Superficial rotavation	2.53	0.32	1.78	0.28	0.20	85	193	28
Zero tillage	2.61	0.31	1.95	0.27	0.20	80	212	49

more gravel and gravel layers at shallower depths in plateau soils, (b) uniform sandy to loamy texture in lower slope soils, as opposed to a more clayey texture with increasing depth in plateau soils, (c) more reduced root growth under natural forest conditions in lower slope soils, as well as (d) a finer pore system and (e) a weaker structure in lower slope soils (derived from MOORMANN et al., 1975). The effects of tillage on these two groups showed considerable differences.

On the lower slope soils, where compaction is a problem, deep tillage gives the best results, while zero and minimum tillage yields are relatively low.

On the plateau soils, where compaction is not such a problem, the natural condition is very suitable for plant growth. If this natural condition can be maintained through mulching, zero and reduced tillage techniques will be very satisfactory (IITA, 1973). If, however, not enough crop residues are available or if they are removed, the natural condition will be adversely affected, whereby compaction and crusting will occur, and these tillage techniques will not be satisfactory. Deep ploughing on the plateau soils might seem a fair treatment in the first few years after clearing, but will after a few years have a deteriorating effect on the soil, because gravel is brought up to the surface layer, the bare soil is exposed and surface crusting occurs, resulting in poor germination and plant growth. The prevention of seedling emergence by surface crusts, which form as a result of the beating effect of raindrops and of the subsequent drying of the compacted layer of oriented particles, was also indicated by SHAW (1952), who mentioned that some of the hardest crusts seem to occur on sandy loam soils.

Shallow tillage techniques might be worth considering for plateau soils. They proved to result in the highest yields and offered the advantage that the yield differences between mulching and no mulching are very small, contrary to zero

FIG. 49. Crop residues decompose rapidly.

tillage and deep tillage. If insufficient crop residues are available to make zero and minimum tillage techniques advisable, shallow tillage could well be the best alternative on the plateau soils.

Possible erosion hazards on both groups of soil are high. On plateau soils zero tillage techniques with mulch protect the soil well against erosion (LAL, 1974), and, as shown by the experiments reviewed, mulching generally increases infiltration and thereby reduces erosion. Shallow tillage techniques indicate lower infiltration rates than the other practices, although no erosion was observed in the shallow treated plots where mulch was incorporated in the surface layers and where a fair amount of mulch was still on the surface.

Lower slope soils give lower infiltration rates than plateau soils, but have lower erosion hazards, because of being in the concave part of the slopes. On these soils deep tillage increases infiltration over zero and shallow tillage practices. Partly due to decomposition of the crop residues, mulching did not result in higher infiltration rates.

Root growth on the lower slope soils was drastically reduced by zero tillage as compared to deep ploughing. On the plateau soils shallow tillage showed the best root growth, followed closely by zero tillage, while deep ploughing showed considerably less root development. Mulching had a positive effect on root growth on the plateau soils, especially in the 0–10 cm layer.

Differences in nutrient uptake following the different tillage treatments on both soils could not be detected.

The lower slope soils have a uniformly sandy loam texture, while the plateau soils become more clayey with increased depth. The pH on both studied soils decreased considerably after a few years of cropping and liming will therefore be necessary. The available P also decreased, while the total N (%) did not show major changes; the CEC on both soils is fairly low.

The experimental data showed that mulching does have a positive effect on soil physical characteristics, especially on the Egbeda soil, while mulching did not appear to have an effect on soil chemical properties.

4.5. POORLY DRAINED SOILS

4.5.1. *Introduction*

Experience in other parts of the world, especially South-East Asia, with poorly drained lowland soils, has been extensive for centuries. Rice has been grown there continuously on levelled and bunded paddy systems, with the tillage operations mainly being carried out by hand or using animal power. The soils, situated in river deltas and inland valleys on fairly clayey deposits, have developed into paddy soils with characteristic paddy profiles (GRIST, 1965; MOORMANN and DUDAL, 1968).

Most of the inland valleys and depressions in West Africa are neither developed nor in use, mainly because of the lack of a good crop and aggravated by human disease problems (malaria, bilharzia, river blindness, etc.). The soils are in general of a fairly sandy to loamy texture (soils of a more clayey texture occur along the major river valleys in West Africa).

These soils, about 5–10% of the agricultural land in West Africa, offer a tremendous potential for increased food production (RUTHENBERG, 1971; CURFS and ROCKWOOD, 1975). Studies, therefore, were initiated on these sandy to loamy soils on newly-cleared inland valleys to study the effects of different tillage practices and of different systems of land development on the growth and yield of rice.

4.5.2. *Hydromorphic soils without water control*

These soils have a fluctuating groundwater table with major differences for wet and dry seasons. During wet seasons temporary flooding may occur, while in the dry season the groundwater table may be lower than 50 cm or more. Tillage studies were done to compare different tillage practices and to study their effect during the various seasons of the year.

4.5.2.1. Tillage effects on yields

An experiment with four tillage treatments was carried out at four different times of the year; during the wet season, during the dry season, during the transition from dry to wet season, and during the transition from wet to dry season.

The four tillage treatments were: zero tillage (no disturbance), hand-hoeing (shallow loosening and mixing, 5–8 cm), rotary tilling (deeper loosening and

TABLE 52. Yields of rice (IR20) in kg/ha following four tillage practices and two methods of crop residue management for different seasons.

Tillage treatment		Crop residue	Wet season	Dry season	Dry/wet season	Wet/dry season
Zero tillage		with		1022	2176	2826
		without	4090	1236	2557	2676
	Mean			1129	2367	2751
Handhoeing		with		1259	2022	2913
		without	5446	1345	2449	2776
	Mean			1302	2236	2845
Rotary tilling		with		893	2761	3695
		without	5491	583	3318	3455
	Mean			738	3040	3575
Ploughing		with		977	3538	3269
		without	5231	757	3628	3061
	Mean			867	3583	3165
Significance levels:		tillage	5%	5%	10%	5%
		LSD (.05)	1098	512	1197 (LSD (.10))	707
		crop residue	–	n.s.	n.s.	n.s.

mixing, 12–15 cm) and ploughing (deeper loosening and inversion, 12–15 cm). Application versus removal of crop residue was introduced as subtreatment to investigate the possible effects of mulch during wet and dry seasons. The yields are summarized in Table 52.

The figures indicate that intensive tillage techniques are preferable for most of the year except during the dry season, when zero tillage and hand-hoeing yield higher, even though at a much lower yield level. Deep tillage techniques break the capillary channels during the dry season and reduce the capillary conductivity of the water from the groundwater level to the rice roots. A second point emerging from the figures is that application of rice straw generally has a negative effect on yields, except for the deeper tillage techniques during the dry season, when the applied straw helps to conserve moisture in the soil.

4.5.2.2. Tillage effects on bulk density

Bulk density samples were taken after harvesting during the dry/wet season experiment. The data in Table 53 are the averages of 9 measurements. The densities varied considerably, with the lowest values following deep tillage. Application of crop residues does seem to increase the bulk density, possibly because of more compaction during the manual weeding operations.

The relation between bulk density and yield is given in Fig. 50, which clearly seems to indicate that decreased bulk density may have had an increasing effect on the yields.

TABLE 53. Bulk density in g/cm³ following four tillage treatments and two mulching practices (following the dry/wet season experiment).

Tillage treatment	Depth (cm)	Crop residue		Average
		with	without	
Zero tillage	0–10	1.51	1.46	1.49
	10–20	1.53	1.52	1.53
Handhoeing	0–10	1.46	1.41	1.44
	10–20	1.51	1.50	1.51
Rotary tilling	0–10	1.40	1.38	1.39
	10–20	1.46	1.45	1.46
Ploughing	0–10	1.37	1.38	1.38
	10–20	1.38	1.44	1.41

Significance levels:
tillage 0–10 : 1%; LSD (.05) = 0.070
10–20 : 1%; LSD (.05) = 0.073
crop residue 0–10 : 10%; LSD (.10) = 0.057
10–20 : n.s.

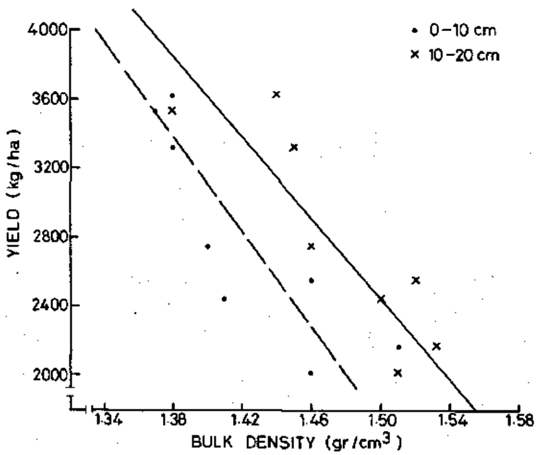


FIG. 50. Relation between bulk density and yield on poorly-drained Jago soil.

4.5.2.3. Land development systems

While the previous experiments were done without any water control, another experiment was started to study the effects of improved water management on the growth and yield of rice for different seasons of the year.

Three management systems were investigated: no bunding and no irrigation, bunding and no irrigation, bunding with irrigation. The yields are presented in Table 54. Yields can be increased greatly by improved management on these hydromorphic soils, the more so during the dry season. Apart from giving the rice plants a better medium in which to grow, resulting in taller plants and more tillers per plant (Table 55), less disease problems occurred in the well managed

TABLE 54. Yields in kg/ha following three management systems for different seasons.

Management System	Wet season '74 (IR20)	Dry season '74/75 (IR20)	Wet season '75 (IR20)
No bunding, no irrigation	1837	1070	2605
Bunding, no irrigation	2392	1214	3513
Bunding, irrigation	3256	3708	4275

TABLE 55. Plant height and tillers per plant at harvest following three management systems (IR20)

Management System	Plant height (cm)		Tillers/plant Wet season 1974
	Wet season 1974	Wet season 1975	
No bunding, no irrigation	88	81	4.40
Bunding, no irrigation	96	84	4.50
Bunding, irrigation	106	90	5.20

systems, thus being an additional factor for increased yields.

As reported in literature (CHAUDHRY and MCLEAN, 1963; GUPTA and KATHAVATE, 1972; MAHAJAN et al., 1970; VARADE and MAHAJAN, 1971) flooded conditions result in a better uptake of nutrients and less losses of nitrogen (PATRICK and WYATT, 1964) compared to unflooded conditions and alternate submergence and drying.

4.5.2.4. Discussion

As already shown, soil tillage to a reasonable depth (about 15 cm) is to be recommended on these hydromorphic soils, except during the dry season, when zero tillage practices can yield higher; the yield levels, however, are much lower then. Mulching in general shows a negative rather than a positive effect on rice yields.

Good water management is a very important factor for increased and steady yields, more so during the dry season, but also during the wet season when water and soil moisture are not limiting.

4.5.3. *Hydromorphic soils with water control*

4.5.3.1. Introduction

As shown in the previous paragraphs the paddy system, with levelling, bunding and good water management, is by far the best in producing high yields, while the yields also seem to be more stable. This land use and development system will become more important in West Africa in the years to come and will ultimately be the final step in land development of the lowland areas, as is already being done in most parts of Asia. The major bottlenecks in West Africa at the moment are the high costs of land clearing and development and of providing water control and water storage. Also, the land tenure system and the farming tradition do not yet stimulate large-scale valley development, since this type of land development should be done, if possible, on the basis of complete units, meaning that for a given lowland area or valley development activities cannot be successful if only done in patches or at random. Seasonal flooding, as well as birds and rodents, can become major obstacles if an area is not developed as a whole.

Studies on soil tillage requirements for this paddy system were initiated on newly cleared and developed land in a river valley; the valley was influenced by graded colluvial fan material, resulting in soils with texture ranging from sandy to clayey.

4.5.3.2. Objectives

Soil tillage for irrigated rice is usually performed in two steps, called primary and secondary tillage (STOUT, 1966).

The main objectives of primary tillage are to loosen the soil, to aerate the soil, which may be essential after high water tables or long periods of poor drainage, to kill weeds, to distribute and incorporate organic matter.

The main objectives of secondary tillage ('puddling') are to help create a hardpan in order to reduce water and nutrient losses, to create beneficial physical, bacterial and chemical conditions for the rice plant, to kill weeds or promote germination of weed seeds in the early stage and subsequently kill them, to distribute and incorporate organic matter in the puddle, to facilitate the introduction and distribution of additional organic fertilizer, to level the field or to make levelling easier, to create those conditions favourable for seed germination or transplanting.

4.5.3.3. Literature review

A lot of soil tillage research has already been done in the existing paddy growing areas, and several of the factors involved in land preparation for irrigated rice have been reported in many previous papers and publications (GRIST, 1965; STOUT, 1966; MOOMAW and CURFS, 1972; TEN HAVE, 1967; MOORMANN and DUDAL, 1968; MOORMANN, 1973; PONNAMPERUMA, 1965; SCHELTEMA, 1974). A short review of some of the most important factors will be given in this paragraph.

Paddy profile formation

The paddy profile existence and the hardpan formation are well known from South-East Asia and Japan and have been described by several authors (GRANT, 1965; KAWAGUCHI and KITA, 1957; KAWAGUCHI et al., 1957; AOMINE and SHIGA, 1959; YAMANAKA and MOTUMURA, 1959; AOMINE, 1962; GRIST, 1965). Among the factors involved are: increase in soil reduction, when the soil is submerged; change in soil colour from yellowish brown to grey, because of the reduction of mainly iron and manganese ($Fe_2O_3 \rightarrow FeO$ and $MnO_2 \rightarrow MnO$); formation of plough-soles and hardpans just under the plough-soles through soil compaction and accumulation of trivalent iron and quadrivalent manganese oxides; destruction of soil structure and the arrangement of sublayers in the ploughed layer ('soil fabric').

AOMINE and SHIGA (1959) describe the soil fabric and divide the ploughed layer into three sublayers: (1) the first sublayer is usually massive with few or more openings. It is completely hydrated when submerged and consists of fine particles, such as silt and clay; when drained, numerous crevices are formed on its surface; (2) the second sublayer is the most important sublayer (for root development and plant growth) from the point of view of the 'soil fabric'. The depth depends on the tillage depth, but is usually 10–15 cm; (3) the third sublayer is generally massive and blocky, indicating bad aeration, even when drained.

GRANT (1965) mentions this stratification process and states that this differentation is seldom noticed in sandy soils. SCHELTEMA (1974) also indicates that a sedimented layer occurs after puddling, by the sedimentation of clay and organic matter particles brought into suspension at puddling at the surface and also between the clods inside the tilled layer after dry/wet tillage.

Hardpans, which may develop in 50 to 100 years under favourable conditions (GRANT, 1965), sometimes become problems, because of very low permeability and inhibited root growth, especially if tillage has always been shallow (MOOMAW and CURFS, 1972). The purpose of a hardpan is to prevent too much percolation of water and nutrients. DE DATTA et al. (1974) and MOORMANN (1973) report that especially in coarse-textured soils the nitrogen losses by leaching may be significant. However, it is necessary to have some percolation of water to prevent an increase in the concentration of toxic substances (MOORMANN and DUDAL, 1968).

Especially wet tillage, through puddling, is reported to hasten the process of hardpan formation (IZUME and HIMEDA, 1968; STOUT, 1966).

Hardpans, in the sense of an irreversible situation, form only in those soils, which are rich in Fe and Mn (MOORMANN and DUDAL, 1968), while a compacted plough-sole or a plough-pan are created by mechanical forces. However, the terms hardpan and plough-pan are often used synonymously.

Tillage depth

Results reported on the effects of tillage depth on rice yields are erratic. The paddy profile in its relation to soil type, texture, structure, organic matter, profile development, drainage conditions, water supply and weed growth is the predominant factor determining the necessary or desired tillage depth. Several reports indicate that deeper cultivation is positively correlated with rice yields (HASSELBACH and VAN AMSON, 1965; IRRI, 1964). Other reports indicate no effects (GRIST, 1965; TEN HAVE, 1967; RAMIAH, 1954; MOOMAW and CURFS, 1972) or possible negative effects (STOUT, 1966, TEN HAVE, 1967; FORTANIER, 1962). Many authors do agree on the fact that deeper cultivation does control weeds better (Ramiah, 1954; Anon, 1971; Stout, 1966) and may therefore result in higher yields.

Soil puddling versus dry tillage

In land preparation for irrigated rice, two distinct practices can be differentiated, dry tillage and wet tillage, usually called 'puddling'.

Several advantages of puddling have been reported (Izume and Himeda, 1963; Sanchez, 1973; Moomaw and Curfs, 1972; Stout, 1966) as follows: it facilitates land levelling, it permits the farmer to work the soil also when it is wet, it helps form a hardpan and prevents water percolation, it controls weeds better, transplanting is easier, organic matter and fertilizers can be mixed thoroughly through the soil, it helps aerate the soil and may help release trapped gases.

Characteristics of puddled soil have been studies by several authors and are reported to be (Sanchez, 1973; Bouma, 1969; Koenigs, 1963): a decreased permeability, an increased soil moisture, a low capillary conductivity, a destroyed system of macro-pores and hence a minimum percentage of air-filled pores, and decreased water losses by evaporation.

Sanchez (1973) reports from his studies on puddling that it does not increase rice growth and soil nutrient uptake under conditions of restricted or no leaching. Puddling, however, decreased losses of applied nitrogen in field and pot conditions, which resulted in higher yields. He concludes that the advantages of puddling tropical rice soils do not seem to be related to increases in nutrient availability but rather to indirect effects of water relations.

Several other authors report that puddling does have a beneficial effect on rice performance (Grant, 1965; Stout, 1966; Aomine and Shiga, 1959) and that soil structure is of little consequence for the growth of the rice plant (Moomaw and Curfs, 1972; Grist, 1965), while others report that soil structure and other physical characteristics are important for rice and that puddling should be kept to a minimum (Fortanier, 1962; ten Have, 1967).

Reports from the heavy clay soils in Surinam (South America), with direct seeded rice, indicate that dry tillage instead of puddling results in an increase in rice yields (Hasselbach and van Amson, 1965; de Wit, 1960; ten Have, 1967). This increase is reported to result from the very low permeability of the clay soils, which promotes reducing conditions and results in an accumulation of toxic substances to which the varieties grown are only partly resistant. Ten Have (1967) states that 'experience has shown, that dry tillage and thorough drying of the soil are of great importance to the rice crop'. On these heavy clay soils Scheltema (1974) also found that following dry tillage nitrogen mineralization of organic matter increased and that the available ammonium in the soil was higher than following wet tillage.

Johnson (1965) reports that many heavy clay soils would take a long time to dry to the point where dry tillage operations could be used. Ten Have (1967) and de Wit (1960) report in this respect that with dry shallow (12–15 cm) tillage the optimum moisture content of the soil is sooner attained, so that work can be started earlier than with deep tillage. TEN HAVE (1967) reports that following dry tillage some puddling might be necessary to break down the hard clods, but this should be kept to a minimum. HASSELBACH and VAN AMSON (1965) report that puddling does not nullify the action of previous dry cultivation.

An advantage of dry tillage is that the equipment for tillage (and planting) can be the same as for upland cultivation, while for wet tillage and puddling a different range of machinery is needed. Another advantage of dry tillage lies in the fact that it offers no constraints to different crops being grown in rotation with rice. Rice is unique in that puddled soil conditions usually act favourably for its growth, in contrast to most other crops (SANCHEZ, 1973).

Time of tillage and organic matter

If crop residue is left on the land and has to be mixed into the soil, it is reported that the land should be tilled at least two weeks before transplanting or direct seeding (MABBAYAD and OBORDO, 1970; PONNAMPERUMA, 1965; ANON, 1966). PONNAMPERUMA (1972) reports that the decomposition of organic matter in a submerged soil differs from that in a well-drained soil in two respects: (1) it is slower and (2) the end products are different. In a well-drained soil the end products are carbon dioxide, nitrate, sulphate and resistant residues (humus), while in submerged soils they are carbon dioxide, hydrogen, methane, ammonia, amines, mercaptans, hydrogen sulfide and partially humified residues. He reports (PONNAMPERUMA, 1965) that accumulation of these substances reaches a peak two to three weeks after flooding and then declines. Some of these decomposition products may, at higher levels of incorporated crop residues, become sufficiently high to injure the young rice plants. These symptoms can occur especially in soils that contain large amounts of organic matter but small amounts of chemically active iron and manganese (ANON, 1966). However, ammonium released by decaying organic matter also reaches its highest concentration in two to three weeks after flooding and tillage (PONNAMPERUMA, 1965; MABBAYAD and OBORDO, 1970). Thus planting at two to three weeks after tillage allows the seedlings to utilize the ammonium released by the decomposing organic matter in the soil. The same authors also note that the fields must remain flooded between the first tillage and transplanting or direct seeding to prevent loss of nitrogen through denitrification. As for the role of organic matter in the soil, MOORMANN and DUDAL (1968) doubt whether it does play an important role in determining the capability of a soil for rice production.

Tillage practices, including reduced tillage techniques

Ploughing was reported to give higher yields, mainly because of better weed control, on heavy clay soils in the Senegal river basin (ANON, 1971), while a non-turning implement was not satisfactory because of poor weed control. TEN HAVE (1967) indicates that for Surinam conditions a mixing operation is better in view of the fact that soil turning retards the decomposition of green matter and promotes reduction, while the drying process of the subsoil may also be more delayed than if this green matter had been mixed with the soil. IZUME and HIMEDA (1968) report that a rotary tiller is better than a plough in areas where the soils are not readily brought into a reductive state or in areas of soils with little organic matter. The results reported on zero and minimum tillage techniques vary to a certain extent due to whether or not suitable chemicals for weed control were available.

IRRI (1967) reports that the number of harrowings can be as low as one if a suitable herbicide is used. MABBAYAD (1967) found no significant differences between tillage treatments on heavy clay soils, and reported minimum tillage yields to be lower only because of the ineffectiveness of the chemicals. MITTRA and PIERIS (1968) report that yields following minimum tillage are similar to normally cultivated plots, but they are lower if Paraquat is omitted. Other succesful applications of zero tillage and minimum cultivation have been widely reported (SETH et al., 1971; BROWN and QUANTRILL, 1973; ELIAS, 1969; DENIZE, 1966).

SETH et al. (1969) report, based on field experiments, that the response to nitrogen was similar for all tillage techniques, while ELIAS (1969) indicates that no yield differences were found with fertilizer, but that without fertilizers minimum tillage techniques were equal or lower in yield than with conventional tillage practices. SCHELTEMA (1974) studied the availability of nitrogen for the rice plants following different tillage treatments and reported that zero tillage resulted in less available nitrogen than the tilled treatments.

Some major advantages of zero and minimum tillage are: reduced labour requirements, double or triple cropping becomes possible, water is saved and the timing of land preparation is more flexible (MITTRA and PIERIS, 1968; BROWN and QUANTRILL, 1973).

JOHNSON (1972) also indicates the potential of zero tillage techniques in soft soils with low mobility.

Soil compaction

The influence of soil compaction on the growth of rice under flooded conditions has been studied and reported by various authors (VARADE and MAHAJAN, 1971; GUPTA and KATHAVATE, 1972; VARADE and PATIL, 1971; MAHAJAN et al., 1970). Working with sandy clay loam soil they showed that rice yields increased up to a bulk density of about 1.7–1.8 gr/cm^3. Related to an increase in bulk density, a reduction in hydraulic conductivity, aeration porosity and capillary porosity was reported, as well as an increased soil strength. The Oxygen Diffusion Rate (O.D.R.) did not show any significant effect on the growth characters of rice (VARADE and MAHAJAN, 1971). Above a compaction of about 1.8 gr/cm^3 the reduction in root growth resulted in significant decreases in grain yield (VARADE and MAHAJAN, 1971). The same authors also indicate that a compaction of about 1.7 gr/cm^3 offers the best conditions for maximum nutrient uptake.

4.5.3.4. Wet versus dry tillage

On newly cleared and developed paddy lands, of sandy loam texture, an experiment was started comparing wet versus dry land preparation for irrigated rice.

4.5.3.4.1. Yields

The first crop following wet and dry tillage (with a rotary tiller) yielded 6210 and 6061 kg/ha respectively for IR20. The second crop showed a significantly higher yield for IR20 and OS6 following wet tillage and also indicated a very high response to nitrogen (Table 56). The third crop again yielded higher following wet tillage (Table 57).

In the first three crops tillage was only done with a rotary tiller. In the fourth crop two tillage practices were applied, rotary tilling and ploughing. The yield figures are presented in Table 58. Wet tillage again showed significantly higher yields than dry tillage. Ploughing resulted in the same yields as rotary tillage under wet conditions, but resulted in significantly higher yields under dry conditions.

Wet versus dry tillage indicated an interaction with nitrogen, suggesting that either nitrogen is used more efficiently after wet tillage and/or that less leaching of water and nutrients occurs through the more compacted plough-sole resulting from wet tillage.

TABLE 56. Yields of rice (IR20 and OS6) in kg/ha following wet and dry tillage and three levels of N(itrogen) on sandy loam soil. (Crop 2).

N (kg/ha) (as urea)	Wet tillage		Dry tillage	
	IR20	OS6	IR20	OS6
0	3984	1702	3382	868
40	4848	1953	3798	1350
80	5608	2414	4130	1728
Mean	4813	2023	3770	1315

Significance levels: for IR20: tillage: 5%; LSD (.05) = 733 kg/ha
nitrogen: 5%; LSD (.05) = 697 kg/ha
for OS6: tillage: 10%; LSD (.10) = 572 kg/ha
nitrogen: 1%; LSD (.05) = 256 kg/ha

TABLE 57. Yield of IR20 in kg/ha following wet and dry tillage and three levels of N (crop 3).

N (kg/ha)	Wet tillage	Dry tillage
0	3212	2736
40	3789	3535
80	4644	4061
Mean	3882	3444

Significance level: tillage: 10%; LSD (.10) = 371 kg/ha
nitrogen: 1%; LSD (.05) = 307 kg/ha

TABLE 58. Yields of IR20 in kg/ha following wet and dry tillage, two tillage practices and two levels of N (crop 4).

Tillage method	N (kg/ha)	Wet tillage	Dry tillage
Jap. reversible plough	0	3616	3145
	80	4556	4330
	Mean	4086	3737
Rotary tiller	0	3590	2629
	80	4301	3992
	Mean	3946	3310
Total average		4016	3524

Significance levels: A. Tillage (wet versus dry): 5%
B. Ploughing versus rotary tilling: 1%
C. Nitrogen (0 versus 80 kg/ha): 1%
D. Interaction A × B: 10%
E. Interaction A × C: 1%

TABLE 59. Yields of IR20 in kg/ha following wet, dry and wet, and dry tillage and two tillage practices (previously wet tilled) (Crop 5).

Tillage	Tillage Method		Mean
	Ploughing	Rotary tilling	
Wet	4766	4473	4620
Dry + wet	4928	4904	4916
Dry	5059	3848	4453
Mean	4918	4408	

In the fifth crop three treatments were applied on the so far only wet or dry tilled fields: dry tillage, wet tillage and dry primary tillage followed by wet secondary tillage. A herbicide spraying, applied wrongly at three weeks after planting, destroyed the crop on the previously dry tilled field and also affected the crop on the previously wet tilled field. The data in Table 59 should therefore only serve as an indication. Ploughing showed a yield increase over rotary tilling, if done dry, as is also shown by crop 4. A combination of dry and wet tillage appeared to give higher yields than the dry or only wet tillage treatment.

4.5.3.4.2. Plant measurements

Tiller countings were done at harvest in crops 2, 3 and 4 (Table 60). For all crops wet tillage indicated more tillers per plant than dry tillage. Also, higher nitrogen rates resulted in more tillers per plant.

Plant height following wet tillage was slightly higher than after dry tillage.

At heading time during crop 5 leaf samples were taken and analysed (Table

TABLE 60. Tiller countings for IR20 at harvest following wet and dry tillage (average of the different nitrogen rates).

	No. of tillers/plant	Crop 2	Crop 3	Crop 4
Wet tillage	total tillers	4.91	5.26	–
	effective tillers	4.35	5.20	4.00
Dry tillage	total tillers	2.98	4.79	–
	effective tillers	2.51	4.69	2.64

TABLE 61. Plant tissue analysis of rice leaves at heading (crop 5).

		Total N %	Total P %	K %	Ca %	Mg %	Mn ppm	Fe ppm
Rotary tilling	dry	1.92	0.24	1.56	0.40	0.19	1320	190
	dry/wet	1.79	0.25	1.60	0.45	0.20	1595	240
	wet	1.82	0.25	1.58	0.40	0.18	1655	190
Ploughing	dry	1.82	0.26	1.50	0.43	0.18	1565	205
	dry/wet	1.77	0.25	1.54	0.39	0.19	1375	200
	wet	1.87	0.26	1.58	0.43	0.18	1930	200

61). No differences in nutrient uptake for the different treatments were indicated, and nitrogen deficiency at heading time (just before the last nitrogen application) was general.

4.5.3.4.3. Soil measurements

After drainage, one week before harvesting, soil moisture was measured during crop 2 in relation to days after drainage (Fig. 51). It indicates that the

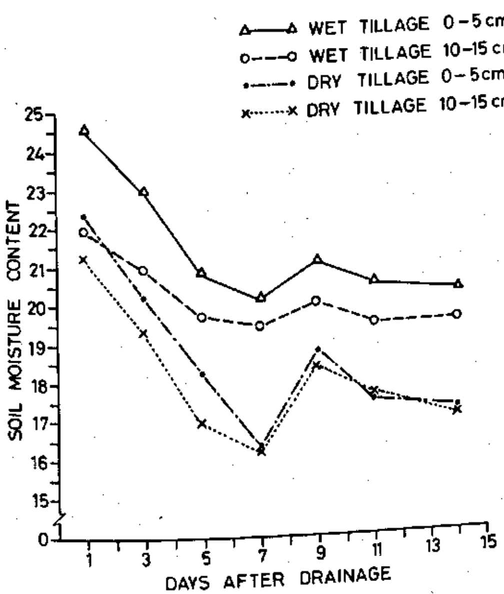


FIG. 51. Soil moisture in relation to days after drainage following wet and dry tillage.

TABLE 62. Total Nitrogen (%) and CEC – values of the top soil layer (3 mm) following wet and dry tillage (Crop 2)

	Wet tillage	Dry tillage
Total Nitrogen (%)	0.086	0.068
CEC (me/100 g)	6.510	5.523

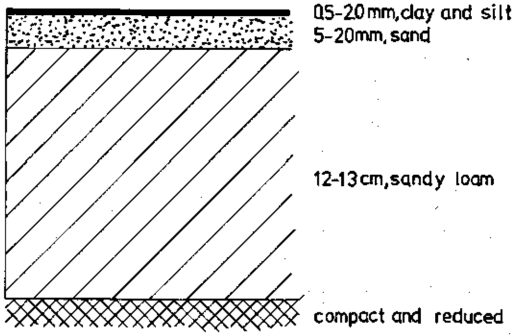


FIG. 52. Layer stratification in a paddy profile on sandy loam soils.

FIG. 53. The top-layer of clay and silt becomes visible upon drying.

TABLE 63. Texture determination of the stratified layers following wet tillage as compared to dry tillage.

	% Sand	% Silt	% Clay
Wet tillage			
Top-layer (0–2 mm)	20.4	46.0	33.6
First sub-layer (2–20 mm)	97.0		
Second sub-layer (2–14 cm)	88.6		
Dry tillage			
Top-layer (0–1 cm)	95.0		
Sub-layer (1–14 cm)	88.7		

moisture content after wet tillage is higher and remains higher after drainage. Hence, one advantage of puddling on these light soils is that more water is stored and maybe available to the plants if a water shortage should occur during the growing season.

While the field was still flooded during crop 2 soil samples were taken from the top 3 mm to determine total nitrogen and CEC (Table 62). The top-layer following wet tillage shows a higher percentage of total nitrogen and higher CEC – values, because of more organic matter and clay in the top 3 mm.

After harvesting crop 2 the layer stratification was studied and four distinct sub-layers were found following wet tillage (Fig. 52):

1. A top-layer, 0.5–2.0 mm thick, consisting of almost pure clay and silt, and rich in organic matter.
2. A first sub-layer, 5–20 mm thick, consisting of pure sand, and poor in organic matter. This layer has not been described in the literature.
3. A second sub-layer of about 12–13 cm thick (working depth of 15 cm), consisting of homogeneous sandy loam soil.
4. A third sub-layer, compact and blocky, reduced.

The top-layer and the first sub-layer come into existence through selective sedimentation according to Stokes Law, after a suspension has been formed through the puddling operation. In Table 63 the results of the mechanical analysis for the different layers are given. It appears as though some clay and silt are leached from the top-layer following dry tillage.

After crop 3 the soil was analysed for texture, pH and organic carbon. All these factors did not show major differences after wet and dry tillage in the 0–15 cm layer (Table 64).

Bulk density measurements were taken after harvesting crop 2 in the most loamy part of the fields at three depths (Table 65). Wet tillage had resulted in a considerably higher compaction in the layer below the plough-sole. Four weeks after planting crop 5 in the previously dry tilled field bulk density measurements were also taken (Table 66). These data indicate that a puddling operation, if only done for one crop, can increase the compaction in the deeper layers and this may have been the cause of the increased yields.

TABLE 64. Mechanical analysis, pH and organic carbon following wet and dry tillage (after crop 3).

	Wet tillage	Dry tillage
% Clay	13.8	14.6
% Silt	9.9	10.2
% Sand	76.3	72.2
pH	5.46	5.70
Organic carbon (%)	0.58	0.55

TABLE 65. Bulk density in g/cm³ following wet and dry tillage after harvesting (crop 2).

Depth (cm)	Wet tillage	Dry tillage
3–7	1.53	1.51
10–15	1.60	1.58
15–20	1.66	1.57

TABLE 66. Bulk density in g/cm³ following wet, dry and wet, and dry tillage on previously dry tilled field (crop 5, four weeks A.P.).

	Depth (cm)	Ploughing	Rotary tilling	Mean
Wet tillage	2–7	1.48	1.49	1.48
	12–17	1.63	1.56	1.60
Dry + wet tillage	2–7	1.49	1.45	1.47
	12–17	1.58	1.57	1.57
Dry tillage	2–7	1.46	1.47	1.46
	12–17	1.56	1.55	1.55
Mean	2–7	1.48	1.47	1.47
	12–17	1.59	1.56	1.57

4.5.3.5. Timing of tillage and crop residue application

The effect of different dates of land preparation and its relation to yield, with different quantities of rice straw being incorporated, was studied on a sandy loam paddy soil.

4.5.3.5.1. Yields

An initial experiment, without crop residue being incorporated, was conducted with four dates of tillage before sowing (40 days, 27 days, 12 days and 1 day before sowing); no yield differences resulted (resp. 5319, 5250, 5387 and 5275 kg/ha).

Following this experiment, three consecutive experiments were carried out with the same treatments on the same plots. Three different amounts of crop residue and four dates of tillage were used. None of the experiments showed significant differences for the tillage and the mulch treatments. The yield results are given in Tables 67, 68 and 69.

TABLE 67. Yields of IR20 in kg/ha following four times of wet tillage before sowing and three levels of organic matter (Experiment 1).

Crop residue	Days elapsing between tillage and sowing				Mean
	42	28	14	2	
A[1]	4107	4579	4512	4895	4523
B[2]	4489	4688	5007	4444	4657
C[3]	4582	4648	4863	4819	4728
Mean	4393	4638	4794	4719	4636

[1] No organic matter applied
[2] Weeds only (resp. 2500, 3085, 3930 and 4425 kg dry weight per ha)
[3] Weeds, see B, plus 4 tons of dry rice straw per ha

TABLE 68. Yields of IR20 in kg/ha following four times of wet tillage before sowing and three levels of organic matter (Experiment 2).

Crop residue (kg/ha)	Days elapsing between tillage and sowing				Mean
	28 + 1	14 + 1	7 + 1	1	
0	4105	4229	4051	4264	4162
5,000 rice straw	4055	4674	4311	4715	4439
10,000 rice straw	4658	5041	4469	5128	4824
Mean	4273	4648	4277	4702	4475

TABLE 69. Yields of IR20 in kg/ha following four times of wet tillage before sowing and transplanting and three levels of organic matter (Experiment 3).

Crop residue (kg/ha)	Days elapsing between tillage and sowing, resp. transplanting				Mean
	28 + 1	14 + 1	7 + 1	1	
Broadcasting					
0	5591	5708	5427	5338	5516
5,000 rice straw	5592	5978	5875	5755	5800
10,000 rice straw	5595	6198	5831	5754	5845
Mean	5593	5961	5711	5616	5720
Transplanting					
0	5956	6075	5655	5492	5795
5,000 rice straw	5960	5603	5923	5572	5764
10,000 rice straw	6301	5708	5902	5014	5731
Mean	6072	5795	5827	5359	5763
Total Average	5833	5878	5769	5488	5742

The first experiment showed no response to the different amounts of crop residues applied and only the tillage date of 42 days before sowing gave a slightly lower yield.

The second experiment did indicate some effect of the crop residue, while the tillage dates also had some effect on yields, with tillage at 28 and 7 days before sowing being lower.

In the third experiment the tillage and mulch effects were studied for broadcast and transplanted rice. Broadcast rice showed a slight mulch effect, while tillage at 14 days before sowing yielded somewhat higher. Transplanted rice did not indicate any mulch effect and only tillage at one day before transplanting showed a yield reduction.

The yield results of the experiments show some variations. In general, incorporation of organic matter does not have a great or clear effect on yields. The effects of different dates of tillage are also not consistent. What can be said is that tillage at more than 3–4 weeks before sowing can result in some yield reduction (possibly because of loss of nitrogen, released by the decomposing crop residues, through alternate drainage and irrigation) and that tillage at one week or less before sowing and transplanting can also result in a decline in yield (possibly because of the detrimental effects of toxic gases released during decomposition).

Tillage at about two weeks before sowing has, in these experiments, resulted in equal or slightly higher yields than the other tillage dates.

4.5.3.5.2. Soil and plant measurements

Leaf samples were taken at heading during the third crop and analysed (Table 70). The analyses did not indicate differences in nutrient uptake for the different crop residue and tillage treatments.

During the third experiment weekly and later fortnightly soil samples were taken in the field to study differences and fluctuations in the organic matter and the percentage total nitrogen (Kjeldahl N) following the different treatments.

The results of these determinations are shown in Figs. 54, 55, 56 and 57. Drainage at sowing time results in a drop in organic matter and in total nitrogen. Upon flooding they both show a sharp rise again. Organic matter shows a slight increase as the rice crop progresses. Incorporation of mulch only results in a

TABLE 70. Leaf analysis at 50% heading following four times of tillage and three levels of crop residue application (Experiment 3).

Tillage before planting (days)	Total N (%)	P (%)	Ca (%)	Mg (%)	K (%)	Mn (ppm)	Fe (ppm)
28 + 1	1.39	0.11	0.87	0.29	1.09	1622	222
14 + 1	1.27	0.10	0.83	0.27	1.01	1557	255
7 + 1	1.24	0.10	0.87	0.28	1.04	1572	253
1	1.32	0.11	0.84	0.26	1.04	1627	295
Crop residue (kg/ha)							
0	1.34	0.10	0.84	0.27	1.04	1573	255
5,000	1.31	0.11	0.86	0.29	1.03	1591	245
10,000	1.26	0.10	0.87	0.27	1.06	1619	269
Average	1.31	0.10	0.86	0.28	1.04	1594	256

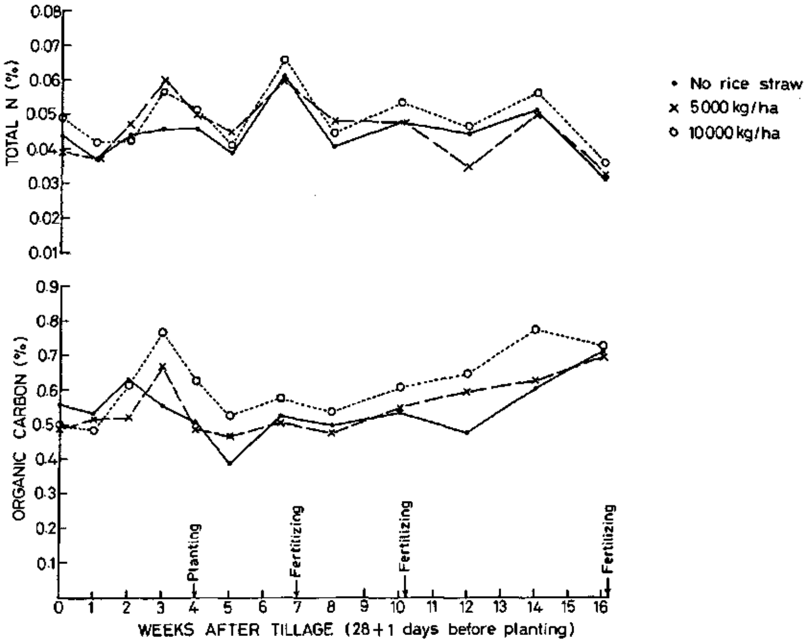


FIG. 54. Organic carbon (%) and total N (%) following three rates of rice straw application and tillage done at 28 days before planting.

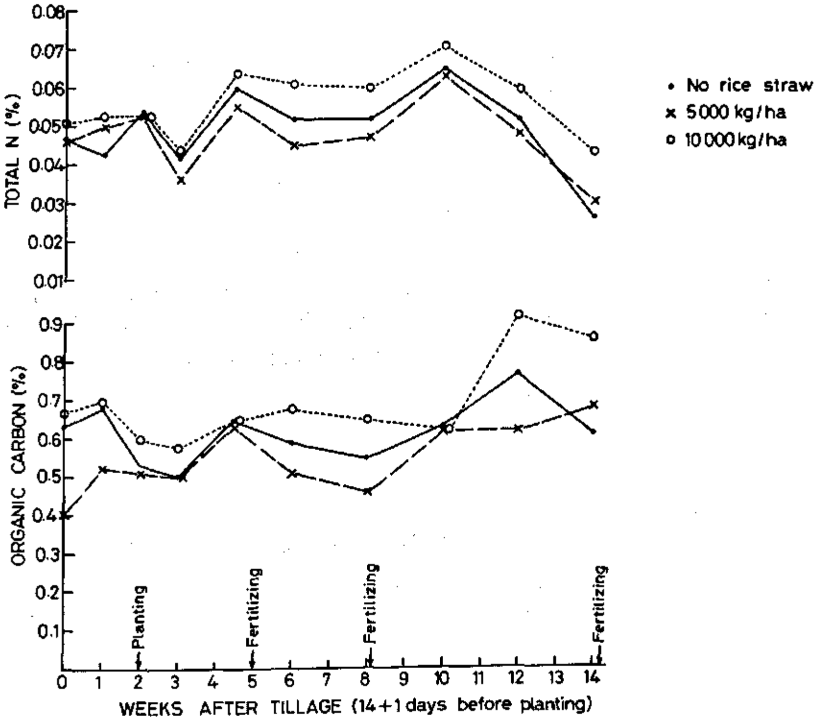


FIG. 55. Organic carbon (%) and total N (%) following three rates of rice straw application and tillage done at 14 days before planting.

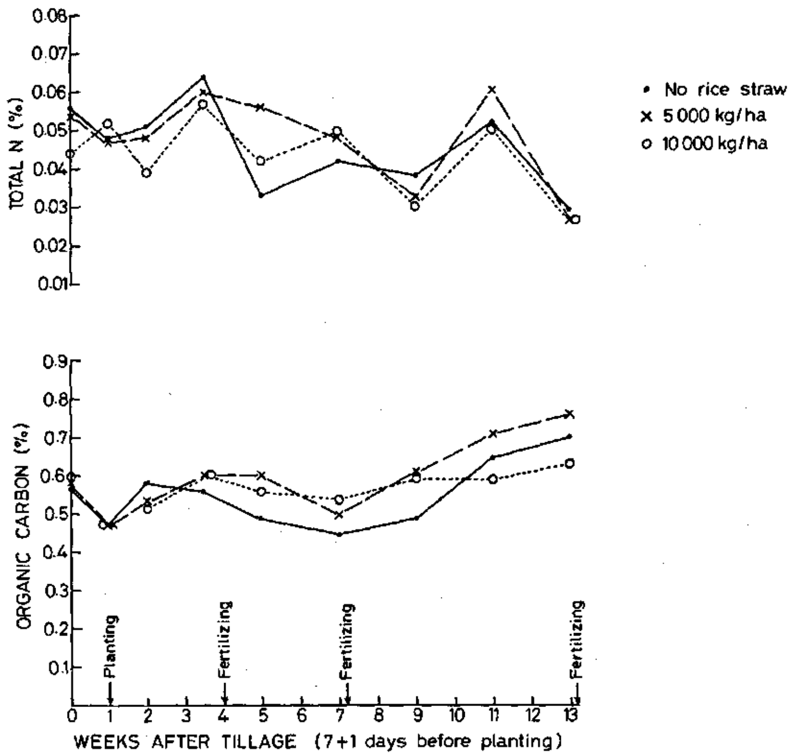


FIG. 56. Organic carbon (%) and total N (%) following three rates of rice straw application and tillage done at 7 days before planting.

very low increase in organic matter in the soil. Total nitrogen shows some decline as the crop grows. Incorporation of mulch only has a relatively small effect on total nitrogen. Tillage at 14 days before sowing appears to result in a slightly higher amount of total nitrogen in the soil.

4.5.3.6. Wet tillage practices

A tillage experiment with four tillage treatments was carried out for four consecutive crops on newly cleared and developed paddy land. The experiments were conducted simultaneously on soils of different texture: on coarse loamy sand, on sandy loam and on sandy clay loam.

The four tillage treatments were:

1. Zero tillage
2. Single pass puddling with rotary tiller
3. Intensive puddling with rotary tiller (3 passes)
4. Wet ploughing and harrowing with reversible plough and puddling harrow (single pass).

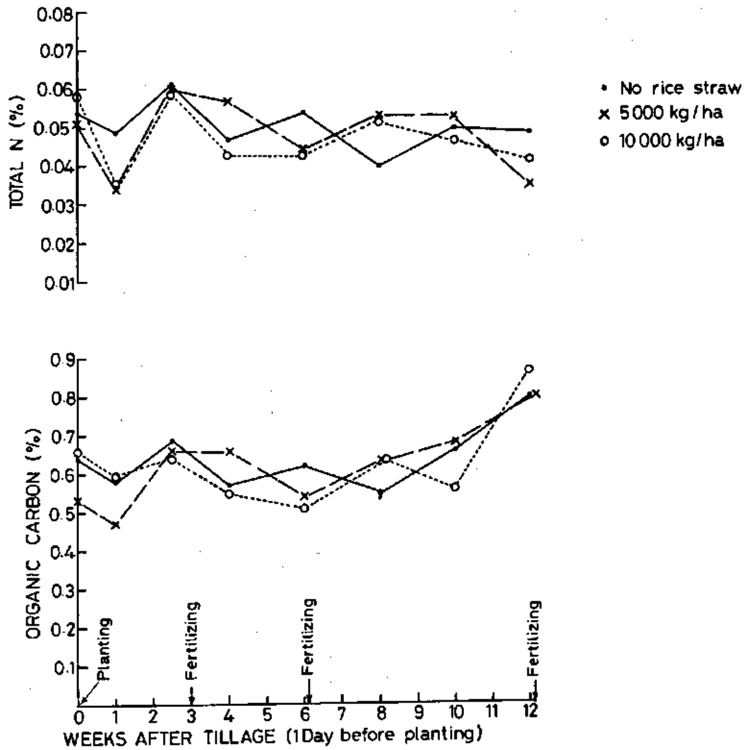


FIG. 57. Organic carbon (%) and total N (%) following three rates of rice straw application and tillage done at 1 day before planting.

TABLE 71. Yields of IR20 in kg/ha following four tillage practices and two levels of N on coarse loamy sand soil for four consecutive crops.

Tillage method	N (kg/ha)	Crop Number				Average	Increase due to N %
		1	2	3	4		
Zero tillage	0	2135	2844	2176	1857	2253	57
	80	3603	3537	3595	3449	3546	
Rotary tiller, 1 pass	0	2892	3250	2647	2871	2915	34
	80	3847	3507	3840	4403	3899	
Rotary tiller, 3 passes	0	3356	3442	2814	2690	3076	38
	80	4016	4131	4009	4781	4234	
Jap. reversible plough	0	3776	3545	2898	3239	3365	31
	80	4225	4003	4027	5335	4398	
Average	0	3040	3270	2634	2664	2902	38
	80	3923	3795	3868	4492	4019	
Yield increase of tillage over zero tillage (%)	0	57	20	28	58	58	
	80	12	10	10	40	18	

4.5.3.6.1. Yields

The yield results of the three soil types and of the different nitrogen rates for the four crops are given in Tables 71, 72 and 73. In Table 74 a summary is presented of all treatments and all crops.

TABLE 72. Yields of IR20 in kg/ha following four tillage practices and three levels of N on sandy loam soil for four consecutive crops.

Tillage Method	N (kg/ha)	Crop Number				Average	Increase due to N %	
		1	2	3	4			
Zero tillage	0	4142	3040	2555	3707	3361	20	36
	40	4538	3822	3603	4138	4025	14	
	80	5032	4303	3954	5007	4574		
Rotary tiller, 1 pass	0	4639	3683	3233	4511	4017	15	24
	40	5141	4173	4052	5164	4633	8	
	80	5207	4533	4581	5638	4990		
Rotary tiller, 3 passes	0	4819	3562	3029	4376	3947	14	31
	40	5124	4217	3813	4806	4490	15	
	80	5482	4944	4544	5658	5157		
Jap. reversible plough	0	4379	3876	3362	4526	4036	12	31
	40	4602	4254	4065	5210	4533	17	
	80	5456	4824	4645	6218	5286		
Average	0	4495	3540	3045	4280	3840	15	30
	40	4851	4117	3883	4830	4420	13	
	80	5294	4651	4431	5630	5002		
Yield increase of tillage over zero tillage (%)	0	11	22	26	21	19		
	80	7	11	16	17	12		

TABLE 73. Yields of IR20 in kg/ha following four tillage practices and two levels of N on sandy clay loam soil for four consecutive crops.

Tillage Method	N (kg/ha)	Crop Number				Average	Increase due to N %
		1	2	3	4		
Zero tillage	0	4651	2823	3360	5459	4073	19
	80	5471	3715	4544	5717	4862	
Rotary tiller, 1 pass	0	4469	3131	4222	5590	4353	16
	80	5299	3507	5452	6012	5068	
Rotary tiller, 3 passes	0	4914	3204	3971	5519	4402	19
	80	5722	4250	5051	5973	5249	
Jap. reversible plough	0	4706	3545	3636	6053	4485	24
	80	5877	4003	5602	6709	5548	
Average	0	4685	3176	3797	5655	4328	20
	80	5592	3869	5162	6103	5182	
Yield increase of tillage over zero tillage (%)	0	1	17	17	5	8	
	80	3	6	18	9	9	

TABLE 74. Yields of IR20 in kg/ha following four tillage practices and 2, resp. 3, levels of N for clayey, loamy and sandy soil types (Average of four crops).

Tillage Method	N (kg/ha)	Soil Type			Total Average	Increase due to N %
		Clayey	Loamy	Sandy		
Zero tillage	0	4073	3361	2253	3229	
	40		4025			34
	80	4862	4574	3546	4327	
Rotary tiller, 1 pass	0	4353	4017	2915	3762	
	40		4633			24
	80	5068	4990	3899	4652	
Rotary tiller, 3 passes	0	4402	3947	3076	3808	
	40		4490			28
	80	5249	5157	4234	4880	
Jap. reversible plough	0	4485	4036	3365	3962	
	40		4533			28
	80	5548	5286	4398	5077	
Total average	0	4328	3840	2902	3690	
	40		4420			28
	80	5182	5002	4019	4734	
Increase due to N (%)		20	30	38		
Yield increase of tillage	0	8	19	38	19	
over zero tillage (%)	80	9	12	18	13	

The following conclusions may be drawn from these series of soil tillage trials:

- the soils with a heavier texture, and situated lower in the valley where leaching is less, yield higher than the lighter soils
- consequently, the effect of nitrogen is higher on lighter soils
- zero tillage, as compared to the tillage practices applied, yields lower, and the lighter the soil the bigger the difference
- zero tillage also shows a slightly higher response to nitrogen than tillage, especially on lighter soils but not on clayey soils
- single pass puddling results initially in lower yields than intensive puddling or ploughing, but the yield differences become smaller and disappear as more crops are grown
- ploughing with harrowing yields about the same as intensive rotary tilling, with ploughing being slightly better.

4.5.3.6.2. Plant measurements

During the last crop tiller countings and plant height measurements were made (Table 75). In general the data show that the plants are taller and have more tillers on the heavier soils; nitrogen increases the number of tillers per plant.

Also during the last crop leaf samples were taken and analysed (Table 76).

TABLE 75. Number of tillers per plant and plant height at 50% heading for IR20 following four tillage practices on clayey, loamy and sandy soil types.

Tillage Method	N (kg/ha)	No. of tillers per plant			Plant height (cm)		
		Clayey	Loamy	Sandy	Clayey	Loamy	Sandy
Zero tillage	0	3.95	3.27	2.30	92	77	75
	40		3.18			77	
	80	4.09	3.12	3.33	89	82	79
Rotary tiller, 1 pass	0	3.79	3.53	2.93	92	85	79
	40		3.38			80	
	80	4.16	3.05	3.02	88	83	84
Rotary tiller, 3 passes	0	4.05	3.10	2.23	90	82	79
	40		3.18			82	
	80	3.97	3.55	2.72	91	83	83
Jap. reversible plough	0	4.07	3.45	2.82	93	81	83
	40		4.05			88	
	80	4.25	3.68	3.25	97	85	85
Average	0	3.97	3.34	2.57	92	81	79
	40		3.45			82	
	80	4.12	3.35	3.08	91	83	83

They showed some minor variations, but major differences in nutrient uptake for the different treatments and the soil types could not be found. As in all other experiments nitrogen was deficient.

4.5.3.6.3. Soil measurements

After harvesting the last crops bulk density measurements were taken in the sandy and loamy fields (the clayey field had got flooded). The results in Table 77 indicate that tillage loosens the top 10 cm layer and compacts the layer below the plough-sole, while zero tillage shows uniform densities in all layers. The sandy soil shows higher bulk densities than the loamy soil (even up to 1.78 g/cm^3).

After harvesting the last crops, soil samples were taken (two measurements per plot and four replications) to be analysed for pH, organic carbon, extractable cations and total N (Table 78). The data in the table are the averages for different depths and the data for tillage are the averages of single pass puddling, intensive puddling and ploughing, since these treatments did not show any significant differences among each other.

The differences between zero tillage and tillage on the three soil types are minor. The more clayey soil types showed a slightly higher organic matter, higher values of most extractable cations and some more total nitrogen.

4.5.3.7. Discussion

The series of experiments reviewed have been dealing with three major problems on newly cleared and developed paddy lands of fairly light texture:

TABLE 76. Leaf analysis at 50% heading following four tillage practices on clayey, loamy and sandy soil types.

Tillage Method	Soil type	Total N(%)		Total P(%)		Ca (%)		Mg (%)		K (%)		Mn (ppm)		Fe (ppm)		
		0	80	0	80	0	80	0	80	0	80	0	80	0	80	kgN/ha
Zero tillage	Clayey	2.09	1.80	0.26	0.26	0.39	0.36	0.20	0.20	1.59	1.62	552	540	220	264	
	Loamy	2.03	1.90	0.23	0.23	0.55	0.55	0.21	0.22	1.60	1.61	800	825	205	195	
	Sandy	2.28	2.29	0.24	0.26	0.51	0.51	0.18	0.19	1.65	1.61	875	710	245	160	
Rotary tiller, 1 pass	Clayey	2.09	1.80	0.26	0.27	0.35	0.51	0.21	0.23	1.48	1.56	572	608	204	184	
	Loamy	1.79	2.08	0.21	0.22	0.61	0.60	0.21	0.21	1.53	1.50	1185	1170	235	245	
	Sandy	2.35	2.04	0.26	0.25	0.50	0.48	0.19	0.18	1.75	1.70	850	695	155	175	
Rotary tiller, 3 passes	Clayey	2.05	2.12	0.27	0.26	0.37	0.43	0.21	0.21	1.56	1.56	552	512	200	244	
	Loamy	1.80	1.90	0.21	0.22	0.56	0.56	0.22	0.20	1.49	1.48	1245	1090	205	230	
	Sandy	1.83	1.93	0.24	0.25	0.55	0.51	0.18	0.19	1.64	1.71	805	750	160	180	
Jap. reversible plough	Clayey	2.03	2.34	0.26	0.27	0.43	0.40	0.27	0.23	1.60	1.61	664	568	228	296	
	Loamy	1.91	2.08	0.21	0.22	0.56	0.56	0.19	0.21	1.45	1.60	1085	1290	230	175	
	Sandy	2.14	2.23	0.25	0.24	0.48	0.48	0.17	0.18	1.71	1.69	665	880	175	215	
Average	Clayey	2.07	2.02	0.26	0.27	0.39	0.43	0.22	0.22	1.56	1.59	585	557	213	247	
	Loamy	1.88	1.99	0.22	0.22	0.57	0.57	0.21	0.21	1.52	1.55	1079	1094	219	211	
	Sandy	2.15	2.12	0.25	0.25	0.51	0.50	0.18	0.18	1.69	1.68	799	759	184	183	
Total Average		2.03	2.04	0.24	0.25	0.49	0.50	0.20	0.20	1.59	1.61	821	803	205	214	

TABLE 77. Bulk densities in g/cm³ following four tillage practices on loamy and sandy soil types.

Tillage method	Depth (cm)	Bulk density (g/cm³)	
		Loamy soil	Sandy soil
Zero tillage	0–9	1.63	1.72
	10–18	1.59	1.71
	19–27	1.61	1.72
Rotary tiller, 1 pass	0–9	1.50	1.60
	10–18	1.57	1.71
	19–27	1.70	1.78
Rotary tiller, 3 passes	0–9	1.52	1.57
	10–18	1.58	1.62
	19–27	1.69	1.73
Jap. reversible plough	0–9	1.51	1.64
	10–18	1.62	1.67
	19–27	1.71	1.78
Significance levels:	0–9	1%	5%
	10–18	10%	5%
	19–27	1%	5%
LSD (.05)	0–9	0.065	0.090
	10–18	0.035 (LSD (.10))	0.066
	19–27	0.030	0.050

TABLE 78. Soil analyses of sandy, loamy and clayey soil types following four crops of rice.

Soil type		pH	Organic carbon %	NH_4OAc extractable cations (me/100 g)					Total N %
				Ca	Mg	K	Na	Mn	
Sandy	zero tillage	6.4	0.55	1.83	0.97	0.09	0.23	0.14	0.056
	tillage	6.1	0.56	1.27	0.76	0.10	0.18	0.26	0.060
Loamy	zero tillage	5.9	0.75	3.65	1.56	0.08	0.23	0.14	0.085
	tillage	5.9	0.71	2.62	1.22	0.06	0.21	0.25	0.076
Clayey	zero tillage	5.9	0.85	3.01	1.87	0.11	0.26	0.57	0.082
	tillage	6.0	0.77	3.29	2.10	0.13	0.30	0.63	0.079

1. Should tillage be done under wet or dry soil conditions?
2. What is the most suitable time for soil tillage before sowing or transplanting?
3. Which tillage technique is most suitable under wet or dry soil conditions?

Undoubtedly, the most important aspect of paddy soil tillage in the first years after the land has been developed, is the creation of a plough-pan to reduce leaching losses of water and nutrients. Wet tillage, as has been shown on these light textured soils, does help to create a plough-pan much quicker than dry tillage and should therefore be recommended, at least until the layer below the plough-sole has been sufficiently compacted so that leaching and leaching losses are within reasonable limits.

Timing of tillage has not proved to be of major importance on these light, not yet well-developed paddy soils, although some yield reductions may occur, with large amounts of organic matter to be incorporated, if tillage is either done too long before sowing or too short before sowing and transplanting. Tillage at about two weeks before sowing seems to offer minimum risks.

Zero tillage techniques, which hardly create a plough-pan, result in lower yields, especially on the lighter soils. Intensive puddling or ploughing in the first years after land development create the desired plough-pan most quickly and consequently result in the highest yields. As more crops are grown and the plough-pan becomes established, less intensive tillage practices are equally good. If for some reason tillage has to be done under dry conditions, ploughing is superior to rotary tilling.

After a plough-pan has been established after some years, soil tillage requirements may change. Dry land preparation or a combination of dry and wet tillage, using a plough for primary tillage, may in the long run become as good or even better than wet tillage alone, even more so on the heavier soil types, where soil reduction might become a problem. It is doubtful whether zero tillage will be advisable, especially on the lighter soils where compaction is a limiting factor.

With increased soil reduction, timing of tillage, if large amounts of organic matter have to be incorporated, may also become more important and primary land preparation at about two weeks before planting (as also indicated in the literature) will be the best time for maximum yields.

4.6. Mechanization aspects

What are the consequences of these results for mechanization?

On the plateau soils, where deep tillage practices are not to be recommended and where zero tillage techniques may be feasible, if enough mulch is available, mechanization can be based on small power sources (small tractors) or even on improved handtools alone.

On the lower slope soils, where deep tillage practices are clearly superior, mechanization based on large power sources(standard four-wheel tractors) seems indispensable, as was also suggested by Smyth and Montgomery (1962).

In the valley bottoms, where under most circumstances soil tillage is advantageous but where deep tillage does not appear to be necessary, mechanization based on small power sources (small tractors) can be feasible.

Under the conditions where small-scale power sources are feasible, large-scale power sources are, of course, also applicable. If areas increase in size or if they have to be prepared in shorter periods of time, large-scale power sources may be the only solution.

5. WEED CONTROL

5.1. Introduction

Under shifting cultivation the difference between soil tillage and weeding is often small, since tillage is mainly done for weed control only and many crops are intercropped. At intermediate technological levels the distinction between tillage and weed control becomes more pronounced, although their interrelationship is still very clear, since the method of land preparation affects the consequent weed growth. At the higher technological levels, where weeding is done exclusively by herbicides, soil tillage can have a different intention and may even be omitted for certain crops.

In this chapter a short literature review on weed growth and weed control will be given and a summary of the weeding investigations carried out, in which two aspects will be discussed; firstly, how can weed growth be kept low by using proper tillage methods, and secondly, how can grown weeds be controlled using appropriate measures.

FIG. 58. Multiple cropping on a traditional farm.

5.2. MATERIALS AND METHODS

The weed studies were done in two types of experiments.

In most tillage experiments, as reviewed in Chapter 4, the efficiency of the different tillage methods and practices to prevent weed growth was measured in the field, by collecting weeds on areas chosen at random. The weed samples were dried and the dry weights used for comparison. Paraquat was sprayed before the start of all experiments.

Some other experiments were conducted for studying the weed growth and for investigating different control measures on efficiency and time requirements. The emphasis in these experiments was on hand, hoe and mechanical weeding as the screening of chemical weed control formulations was already being carried out and reported (MOODY, 1974; IITA, 1971, 1972, 1973, 1974).

5.3. LITERATURE REVIEW

On a world wide basis the losses of potential crop production per region due to weeds are reported to be (FAO, 1970b):

for North and Central America	8.0%
South America	7.8%
Europe	6.8%
Africa	15.7%
Asia	11.3%
Oceania	8.3%
U.S.S.R. and the People's Republic of China	10.1%

MOODY (1973) reports weeds to be one of the major problems of tropical agriculture and that the inability to control weeds will be one of the greatest obstacles to continuous cultivation in the tropics. RUTHENBERG (1971) reports that many shifting cultivation systems manage with little weeding, as the fallow suppresses the growth of weeds and as fire clearance often leaves the soil weed-free, but that the effort spent on land preparation and weeding increases as the period of cultivation increases. NYE and GREENLAND (1960) and DE GROOT (1974) mention that this increased weed growth is often the primary reason for a patch of land being abandoned. NYE and GREENLAND (1960) also state that it is frequently difficult to decide whether falling yields are due to weeds or to declining soil fertility. FORTANIER (1962) also notes the increased weed problems after clearing, and reports grasses to become dominant over broad-leaved weeds in a few years time. This change in weed flora was also reported by MOODY (1973). Weed growth and weeding is reported to be the major restriction limiting the cropping area that can be effectively cultivated by the small farmer and that weeding is the most severe limitation to farmers using animal-power (KLINE et al., 1969). The time spent on weeding, as derived from farm surveys in Western Nigeria, accounts for more than half of the total labor inputs (IITA,

FIG. 59.
Children weeding in a farmer's field with a cutlass.

1974), and FLINN (1974) mentions that hired and contract labour are mostly used for weeding. Yield losses due to weeds are very significant. JOHNSON and LINK (1970) report that weeds reduced irrigated rice yields by about 50–90 kg/ha for each week that the crop needed weeding.

RAMIAH (1954) and CHABROLIN (1969) indicate that the main problem with upland rice is weed control and MOODY (1974) and RENAUT (1972) report average yield losses for upland rice due to uncontrolled weed growth to be around 50–60%, while in some instances complete loss has occurred.

Weeds compete with rice for light, nutrients and water (GRUMMER, 1969). The uptake of nutrients to produce one kilogram of dry matter is about twice as high for weeds as for rice (GRUMMER, 1969) and especially in the initial growth stages weeds have a higher uptake of nitrogen than rice (IKE, 1963; MUKHAPADHYA and VERMA, 1967), indicating that the presence of weeds, especially in the initial growth stages, will result in reduced growth and consequently in a decreased yield of the rice. CHAKRABORTY (1973) reports, however, that rice suffers from severe

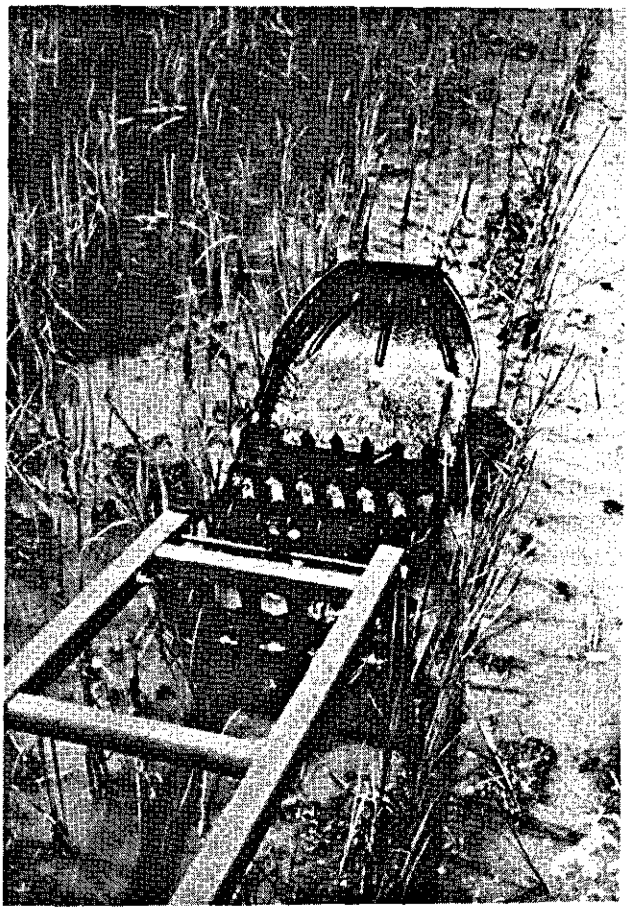


FIG. 60. Rotary weeder for irrigated rice.

competition for nitrogen by weeds throughout the growth under dry land conditions and DE DATTA (1975) recommends that fertilizer should not be applied if weeds are not adequately controlled. Competition for water may not be a problem under irrigated conditions, but can be very significant under dryland conditions (IKE, 1963).

DUFF and ORCINO (1971) indicate that the timing rather than the frequency of weeding is a major determinant of effective weed control for rice. Recommendations have been made for the first weeding to be done 2–3 weeks after sowing followed by a second weeding three weeks later and if necessary a third one (MOOMAW, 1971; ANON, 1973). RENAUT (1972) illustrates that one weeding for upland rice is not enough and that the yield increase through a second weeding is substantial.

For irrigated rice probably the most important factor in weed control is good water management, although good land preparation reduces weeds and also reduces labour used in controlling the weeds that remain (IITA, 1974; JOHNSON and LINK, 1970). Puddling especially is reported to be a very good weed control measure (RAMIAH, 1954; POTHECARY, 1970). POTHECARY (1970) also indicates that a combination of wet and dry tillage has been found to give the best results. STOUT (1966) and GRIST (1965) mention that secondary tillage two to three weeks after primary tillage may be the most effective in that germinated weed seeds can then be destroyed easily.

Deep ploughing under irrigated conditions, preferably with a mouldboard plough instead of a disc plough (POTHECARY, 1970), is reported to result in less consequent weed growth than shallow tillage techniques (RAMIAH, 1954; STOUT, 1966). For upland conditions deep ploughing also gives a most efficient weed control (SÉGUY, 1970; KOUWENHOVEN, 1973), although LAL (1975) and ABEYRATNE (1962) condemn this practice as a weed control measure, because of the erosion hazards. KUIPERS (1974) makes a distinction between annual weeds (seed propagated weeds) and perennial weeds (rhizomatous weeds) and mentions that ploughing is most effective in the case of seed propagated weeds, while rotavators or tine cultivators can be more effective for the control of rhizomatous weeds.

TOURTE et al. (1967) indicated that tillage at the end of the wet season can be a better practice against weed growth during the next season than tillage at the beginning of the wet season.

Planting techniques can influence weed growth. Transplanted rice is reported to be less affected by weed growth than direct seeded rice (GRIST, 1965; IITA, 1974). Planting in rows results in less weed competition and requires less weeding time than broadcasting, provided the same seed rates are used (PILLAINAYAGAN, 1974; GRIST, 1965; CHABROLIN, 1969), while broadcasting naturally rules out mechanical weeding (CHABROLIN, 1969). Closer row spacing would also increase the competitive ability of the rice crop but would virtually exclude anything but herbicides as a means of weed control (MOODY, 1974). Most attempts with inter-row weed control in upland rice have not been successful (RENAUT, 1972; LE MOIGNE, 1972; CHABROLIN, 1969). In irrigated rice, rotary weeders have been used with success, although some supplementary hand-weeding around the plants may still be necessary (GRIST, 1965), more so if the rice is direct seeded.

In general, many authors agree on the point that chemical weed control, especially for upland rice will be most desirable and that these labour saving techniques will be applied extensively in the future (MOODY, 1973; DE GROOT, 1974; VAN RIJN, 1974; PAPADAKIS, 1966; RENAUT, 1972); it may also be the only method of repressive weed control for large-scale rice production (MOODY, 1974). In experiments, it was illustrated that the best herbicide treatments were superior to two or three hoe-weedings for irrigated and upland rice (IITA, 1974).

The success of any reduced or zero tillage technique depends mainly on the availability of suitable chemicals for weed control (ANON, 1970; BAEUMER and BAKERMANS, 1973; ABEYRATNE, 1962). VAN RIJN (1974) mentions that chemically killed weeds in zero tillage can act as an additional mulch and LAL (1975) and IITA (1974) indicate that a good surface cover from crop residues may reduce weed growth.

Weeds cause greater yield losses in maize under low than under high soil fertility (IITA, 1974), and the biggest increase in food production can be obtained if the losses due to weeds can be reduced on the small farms where fertility is low and where weeds still cause most damage (DE GROOT, 1974).

5.4. Soil tillage and weed growth

5.4.1. *Rice on well-drained soils*

Bush re-growth and weed growth were sampled in the experiment, as described in par. 4.4.3.2. Bush re-growth samples were taken each year at the end of the dry season, before the experimental plot was being tilled and planted again. The data are given in Table 79. Deep tillage practices significantly reduce the amount of bush re-growth as compared to shallow and zero tillage; rotavation is as effective as deep ploughing. Shallow tillage with high-powered tractors is more efficient than shallow tillage with low-powered tractors, which tend to go more over the roots and stumps. Zero tillage is at least as effective in repressing bush re-growth as shallow low-powered tillage treatments.

Weed samples were also collected at three and six weeks after planting and at harvesting and the weed growth figures are given in Tables 80, 81 and 82. Weed growth is lowest following deep tillage, followed by shallow tillage, hand-hoeing and lastly zero tillage.

It should be noted that tillage still has an effect on the weed growth even after one or two manual weedings have been done.

In the first year after clearing weed growth in rice after drilling and broad-

TABLE 79. Bush re-growth in g/m^2 following ten tillage treatments on Egbeda soil.

Tillage treatment	Year after clearing			
	1	2	3	4
1. ZT	68.5	90.8	96.8	76.8
2. HH	85.2	91.9	83.8	113.8
3. RT-2	52.5	79.1	74.2	115.0
4. PL-2	53.5	36.0	64.3	71.3
5. MPL-4S	30.8	18.8	22.1	31.8
6. MPL-4D	48.9	4.7	7.1	12.8
7. DPL-4S	38.0	14.9	32.6	29.4
8. DPL-4D	57.3	5.0	15.0	1.1
9. RoI-4	6.3	1.2	7.5	3.5
10. RoSS-4	13.4	2.7	9.2	0.0
Mean	45.4	34.5	41.3	45.5
Significance level	1%	1%	1%	1%
LSD (.05)	18.2	44.3	24.6	48.8

TABLE 80. Weed growth in g/m² at three weeks after planting following ten tillage treatments on Egbeda soil (rice)

Tillage treatment	Year after clearing				Mean
	1	2	3	4	
1. ZT	78.0	54.8	33.8	61.6	57.1
2. HH	14.0	40.4	17.4	18.2	22.5
3. RT–2	24.0	27.0	3.0	11.3	16.3
4. PL–2	16.0	29.4	1.8	7.7	13.7
5. MPL–4S	17.0	19.6	2.5	4.1	10.8
6. MPL–4D	19.5	18.6	0.4	0.2	9.7
7. DPL–4S	18.0	21.4	2.6	8.3	12.6
8. DPL–4D	18.5	11.8	0.8	1.4	8.1
9. RoI–4	12.5	7.6	0.5	2.6	5.8
10. RoSS–4	10.0	26.2	0.4	8.4	11.3
Mean	22.8	25.7	6.3	12.4	16.8
Significance level	n.s.	n.s.	1%	1%	
LSD (.05)	–	–	8.1	10.3	

TABLE 81. Weed growth in g/m² at six weeks after planting following ten tillage treatments on Egbeda soil (rice).

Tillage treatment	Year after clearing			Mean
	1	2	3	
1. ZT	37.5	30.9	21.1	29.8
2. HH	36.5	21.1	11.6	23.1
3. RT–2	49.5	19.9	10.9	26.8
4. PL–2	24.0	19.3	6.9	16.7
5. MPL–4S	56.5	18.2	4.6	26.4
6. MPL–4D	26.5	12.5	2.5	13.8
7. DPL–4S	36.5	16.7	5.1	19.4
8. DPL–4D	36.5	10.7	4.0	17.1
9. RoI–4	17.0	9.7	2.3	9.7
10. RoSS–4	31.5	16.1	4.6	17.4
Mean	35.2	17.5	7.4	20.0
Significance level	n.s.	n.s.	1%	
LSD (.05)	–	–	9.0	

casting at a rate of 65 kg/ha was the same, while no weeding resulted in a yield loss of about 60% compared to an adequate weeding at 3 and 6 weeks after planting. The relation between dry weed weights at harvest (X in g/m²) and the yields (Y in kg/ha at 14% M.C.) for all plots was the following: $\ln Y = 6.864 - 0.000671 X$ with $R^2 = 0.87$.

In the second year after clearing time measurements for hand-weeding were

TABLE 82. Weed growth in g/m² at harvesting following ten tillage treatments and manual weeding at 3 and 6 weeks after planting, on Egbeda soil (rice).

Tillage treatment	Year after clearing		Mean
	2	3	
1. ZT	170	292	231
2. HH	80	248	164
3. RT–2	49	321	185
4. PL–2	43	174	109
5. MPL–4S	48	200	124
6. MPL–4D	17	144	81
7. DPL–4S	47	199	123
8. DPL–4D	13	145	79
9. RoI–4	8	142	75
10. RoSS–4	14	102	58
Mean	49	197	123
Significance level	1%	5%	
LSD (.05)	115	118	

made and the relation at six weeks after planting between dry weed weights (X in g/m²) and time required for weeding (Y in manhours/ha) for all plots was: for IR20: $Y = 13.75\,X + 83.56$ with $R^2 = 0.55$ and for OS6: $Y = 13.98\,X + 82.87$ with $R^2 = 0.67$.

These linear relations indicate that a good tillage practice can considerably reduce the time requirements for weeding. In the second year after clearing no yield differences were found between keeping the plots weed-free and weeding at three and six weeks after planting. In the third year, however, the same treatments did show differences, especially for the shallow and zero tillage techniques, indicating that weed growth had become more severe, while a change to more grasses was also noticed.

In the fourth year after clearing, the plots, where crop residues were left, showed about twice as many weeds following zero tillage and hand-hoeing, while all other tillage treatments did not show increased weed growth when crop residues were left in the plots.

Similar results were also observed in another trial conducted on a different soil type, as described in par. 4.4.3.3. Weed growth was sampled in this experiment at three and six weeks after planting (Table 83). These data also show that deep tillage provided the best weed control, while zero tillage and tine cultivation proved the least effective.

The data on weed growth in the experiment, as described in par. 4.4.4.2, are are presented in Table 84. In year 2 two manual weedings were done, at 3 and 6 weeks after planting, while in year 3 three manual weedings were done, at 2½, 5½ and 8½ weeks after planting.

Ploughing was the most efficient weed control measure, and zero tillage showed in year 3 less weed growth than shallow tillage. Mulching indicated a slight

FIG. 61. Broad-leaved weeds are predominant in the first few years after clearing.

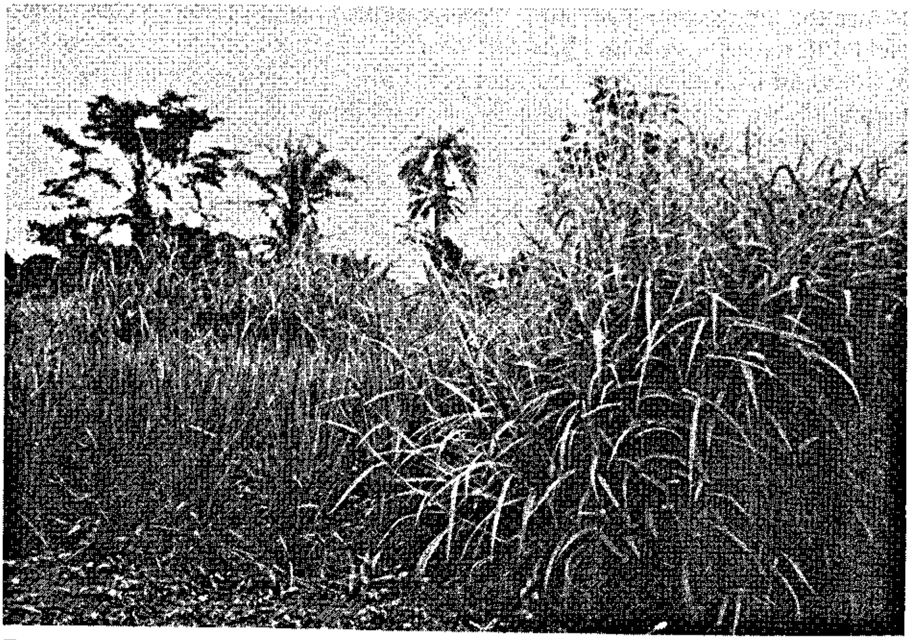


FIG. 62. Grasses become the predominant weed species within a few years after clearing.

TABLE 83. Weed growth in g/m² following seven tillage treatments on Iwo soil. (Average of 4 tillage times)

Tillage treatment	Weed growth in g/m²	
	3 weeks A.P.	6 weeks A.P.
Hand-hoeing	29.1	25.5
Disc ploughing (10 cm)	22.5	22.1
Disc ploughing (25 cm)	8.6	13.4
Rotavation (15 cm)	20.9	17.7
Mouldboard ploughing (15 cm)	12.8	14.3
Tine cultivation (15 cm)	27.6	35.7
Zero tillage	37.3	36.2
Significance level	5%	n.s.
LSD (.05)	15.6	–

TABLE 84. Weed growth in rice in g/m² following two dates of tillage, three tillage practices, with and without crop residue left, on Iregun soil.

Tillage treatment	Year after clearing 2		3		
	3 weeks A.P.	6 weeks A.P.	2½ weeks A.P.	5½ weeks A.P.	8½ weeks A.P.
1. PT_1	13.8	15.0	16.1	32.0	27.5
2. PT_2	5.3	15.4	8.6	15.8	40.0
3. PT_1R_i	4.8	14.6	12.2	36.0	33.4
4. PT_2R_i	2.5	38.5	19.5	40.3	40.9
5. PT_1Ro	4.5	26.2	18.6	34.3	35.6
6. PT_2Ro	3.0	19.2	17.5	25.5	88.7
7. ST_1	11.8	11.9	41.9	40.3	100.9
8. ST_2	5.0	21.7	20.6	29.0	87.5
9. ST_1R_i	7.8	12.9	39.7	54.3	117.5
10. ST_2R_i	7.8	34.8	49.4	57.3	141.6
11. ZT	19.8	31.2	27.5	26.5	51.6
12. ZTR	23.3	42.7	35.0	50.3	91.9
Ploughing	5.7	21.5	15.4	30.7	44.4
Superficial rotavation	8.1	20.3	37.9	45.2	111.9
Zero tillage	21.6	37.0	31.3	38.4	71.8
Tillage at end wet season	8.5	16.1	25.7	39.4	63.0
Tillage at beginning wet season	4.7	25.9	23.1	33.6	79.7

increase in weed growth following ploughing, but for zero tillage, and to a lesser extent for shallow tillage, increased weed growth due to mulching was considerable. Tillage at the end of the wet season did not decrease weed growth for the subsequent crop as compared to tillage at the beginning of the wet season. At the end of the dry season, following year 2, distinct differences in weed species

TABLE 85. Weed species and weed growth in g dry weight per m² following two tillage times and three tillage treatments (end dry season).

		Tillage treatment				
		P_1T_1 1, 3, 5	P_1T_2 2, 4, 6	ST_1 7, 9	ST_2 8, 10	ZT 11, 12
Total weed growth	(gr/m^2)	280	499	270	433	528
Croton Lobatus	(no/m^2)	18	–	–	–	–
	(gr/m^2)	184.5	–	–	–	–
Talinum triangulare	(no/m^2)	1	20	12	24	17
	(gr/m^2)	35.6	143.3	101.2	111.9	114.9
Spigelia anthelmia	(no/m^2)	43	–	4	–	–
	(gr/m^2)	9.4	–	1.8	–	–
Other weed species (mainly grasses)	(gr/m^2)	50.0	355.4	167.2	321.2	412.4

were noticed in the various treatments and weed counts were therefore taken and weed samples collected (Table 85).

In the plots tilled at the end of the wet season different weed species had grown than in the plots which still had to be tilled at the beginning of the wet season. The already ploughed plots had almost exclusively *Croton Lobatus* and *Spigelia anthelmia*, while the already shallow tilled plots showed some *Spigelia anthelmia*.

FIG. 63. Mainly *Croton Lobatus* as a result of tillage at the end of the wet season.

The not yet tilled plots did not show any *Croton Lobatus* or *Spigelia anthelmia*, but had a predominance of *Talinum triangulare*, while this weed species was reduced by tillage at the end of the wet season, especially by ploughing.

Before weeding at 8 weeks after planting in year 3, weeds were examined again for the various treatments and the determinations indicated that *Talinum triangulare* was still rare in the plots ploughed at the end of the wet season, that the mulched plots, especially with zero and shallow tillage, had much less *Spigelia anthelmia*, that the plots ploughed at the beginning of the wet season had less *Ageratum conyzoides* than with all the other treatments and that ploughing in general had a lower incidence of another grown weed species, *Digitaria horizontalis*, than shallow and zero tillage. These observations were, however, not quantified.

5.4.2. *Rice on poorly-drained soils*

Weed samples taken in the experiments, as discussed in par. 4.5.2, indicated that, without water control and with Paraquat application before the start of the experiments, different tillage techniques do not influence weed growth to a great extent, although rotary tilling and ploughing can reduce weed growth to some extent (Table 86). Leaving the crop residue in the field results in most cases in slightly more weeds than if crop residue is removed.

The most important effect on weed growth comes from puddling and good water control, as indicated in Table 87.

TABLE 86. Weed growth in g/m² following four tillage practices on poorly-drained soils.

Tillage treatments	Dry season		Dry/wet season		
	3 w. A.P.	6 w. A.P.	3 w. A.P.	5 w. A.P.	8 w. A.P.
Zero tillage	25	63	20	66	95
Hand-hoeing	12	62	15	82	80
Rotary tilling	10	63	8	51	79
Ploughing	5	58	9	70	68
Average: with crop residue	8	71	16	71	85
without crop residue	18	52	9	63	76

TABLE 87. Weed growth in g/m² following three land development systems on poorly-drained soils.

		2½ w. A.P.	5 w. A.P.	8 w. A.P.	at harv.
No bunding, no irrigation	wet season 1974	92	24	30	92
No bunding, no irrigation	wet season 1975	32	40	46	168
Bunding, no irrigation	wet season 1974	85	24	23	39
Bunding, no irrigation	wet season 1975	20	19	23	103
Bunding, irrigation	wet season 1974	30	13	18	5
Bunding, irrigation	wet season 1975	8	20	16	67

TABLE 88. Weed growth following wet, dry and wet, dry tillage at two weeks after planting (crop 5).

Tillage	Previously wet tilled		Previously dry tilled		Mean
	ploughed	rot. till.	ploughed	rot. till.	
Wet	11.3	9.0	7.8	9.8	9.5
Dry and wet	6.5	4.0	6.8	3.5	5.3
Dry	14.3	9.5	17.8	9.3	12.8
Mean	10.7	7.5	10.8	7.5	

In the experiments with good water control (par. 4.5.3.) intensive puddling and ploughing with harrowing are equally effective and result in about half the amount of weeds as zero tillage and single pass rotary tilling. The better the water control, the less weed incidence occurred and the heavier soils consequently resulted in less weed growth than the lighter soils.

A combination of dry and wet tillage (par. 4.5.3.4.) resulted in less weeds than wet tillage alone, while dry tillage had the highest amount of weeds grown (Table 88).

5.4.3. *Discussion*

Soil tillage practices have a considerable effect on weed growth and this effect also remains after one or two manual weedings have been done.

On the well-drained soils, deep tillage is most effective in controlling weed growth. However, deep tillage practices may not be desirable on the plateau soils, as discussed in par. 4.4.5., which suggests that for any larger scale production on these soils herbicides will have to be used. On the lower slope soils deep tillage is feasible and can play a role in controlling and reducing weed growth.

Different dates of tillage did not result in important differences in the quantitative amounts of weeds grown, although the weed species grown following tillage at the end of the dry season and tillage at the beginning of the wet season were markedly different.

On the poorly-drained soils the most important factors in weed control are wet tillage (puddling) and good water management. Intensive puddling and ploughing with harrowing provide the best control, while zero and reduced tillage techniques must be supplemented with herbicides.

5.5. WEED GROWTH AND WEED CONTROL

5.5.1. *Manual and mechanical weed control in rice*

On well-drained soils rice was used as the test crop to evaluate hand, hoe and mechanical weed control methods. The rice was planted at row distances of 30 cm.

TABLE 89. Weed growth in g/m^2 following seven weeding treatments, applied at three and six weeks after planting (Variety: IR20).

Weeding treatments	Weed growth (g/m^2)	
	6 w. A.P.	at harvest
Hand-weeding	12.2	42.2
Hoe-weeding	12.8	27.8
Blade weeding (by hand), 1-row	39.5	106.1
Blade weeding (with hand-tractor), 3-row	53.4	170.0
Tine weeding (by hand), 1-row	60.0	128.9
Tine weeding (with hand-tractor), 3-row	58.3	165.0
Rotary weeding (with hand-tractor), 3-row	51.2	96.1

In an initial experiment on newly-cleared land seven weeding treatments were applied at three and six weeks after planting, and weed growth and time requirements were measured. The weed growth data are presented in Table 89. Because of working on newly-cleared land and because of drought periods, weed growth was fairly low, an average for all plots of 46 g/m^2 at three weeks after planting.

Most mechanical weed control methods did not prove to be very effective in comparison to hand and hoe-weeding. Rotary weeding was the best of the mechanical treatments; the use of a hand-tractor for blade and tine weeding proved less effective than hand-pushing.

Time requirements for weeding were quite low, about 140 hrs/ha for each hand-weeding, about 100 hrs/ha for each hoe-weeding and about 60–70 hrs/ha for a double-pass with a hand-pushed blade or tine weeder. Because of drought stress the rice yields were very low, between 200 and 500 kg/ha (variety: IR20).

Based on this experiment another trial was conducted on the same land, comparing the same weeding treatments, but also at more intensive application levels. Three methods of land preparation were done: strip tillage, minimum cultivation with a tine-cultivator (double-pass) and ploughing with harrowing.

The weeding treatments were:

1. Hand-weeding, at 3 and 6 weeks A.P. (HaW, 2 ×)
2. Hand-weeding, at 2, 5 and 8 weeks A.P. (HaW, 3 ×)
3. Hoe-weeding, at 3 and 6 weeks A.P. (HoW, 2 ×)
4. Hoe-weeding, at 2, 5 and 8 weeks A.P. (HoW, 3 ×)
5. Tine weeding, by hand, at 3 and 6 weeks A.P. (TWH, 2 ×)
6. Tine weeding, by hand, at 2, 5 and 8 weeks A.P. (TWH, 3 ×)
7. Tine weeding, with hand-tractor, at 2, 5 and 8 weeks A.P. (TWT, 3 ×)
8. Blade weeding, by hand, at 2, 5 and 8 weeks A.P. (BWH, 3 ×)
9. Blade weeding, with hand-tractor, at 2, 5 and 8 weeks A.P. (BWT, 3 ×)
10. Horizontal rotary slashing, at 2, 5 and 8 weeks A.P. (RSH, 3 ×)
11. Rotary weeding, with hand-tractor, at 3 and 6 weeks A.P. (RWT, 2 ×)
12. Rotary weeding, with hand-tractor, at 2, 5 and 8 weeks A.P. (RWT, 3 ×)

TABLE 90. Weed weights in g/m² following twelve weeding treatments. (Average of three tillage treatments)

Weeding treatment	Weed weights in g/m²			
	5 w. A.P.	6 w. A.P.	8 w. A.P.	at harvest
1. HaW, 2 ×		21		213
2. HaW, 3 ×	15		15	143
3. HoW, 2 ×		35		186
4. HoW, 3 ×	23		20	114
5. TWH, 2 ×		72		491
6. TWH, 3 ×	92		100	492
7. TWT, 3 ×	61		192	501
8. BWH, 3 ×	65		167	581
9. BWT, 3 ×	42		125	412
10. RSH, 3 ×	52		136	470
11. RWT, 2 ×		76		530
12. RWT, 3 ×	48		85	371
Mean	50	51	105	375
Strip tillage	85	70	154	472
Minimum cultivation (cultivator)	37	48	83	345
Conventional ploughing	28	35	78	309

TABLE 91. Time requirements in hrs/ha for different weeding treatments. (Average of three tillage treatments)

Weeding treatment	Weeks after planting					Total
	2	3	5	6	8	
1. HaW, 2 ×		288		183		471
2. HaW, 3 ×	244		174		122	540
3. HoW, 2 ×		105		148		253
4. HoW, 3 ×	79		101		85	265
5. TWH, 2 ×		32		31		63
6. TWH, 3 ×	28		21		34	83
7. TWT, 3 ×	20		16		18	54
8. BWH, 3 ×	28		21		35	84
9. BWT, 3 ×	24		18		24	66
10. RSH, 3 ×	92		132		123	347
11. RWT, 2 ×		15		15		30
12. RWT, 3 ×	11		11		11	33

The weed weights at two weeks A.P. were an average of 20 g/m² and at three weeks A.P. an average of 46 g/m². The weed weights at 5, 6 and 8 weeks A.P. and at harvesting are given in Table 90 and the time requirements for weeding in Table 91.

Hand-weeding and hoe-weeding are most effective for weed control, but also require the most time, with hand-weeding about 500 hrs/ha and hoe-weeding about 250 hrs/ha. More intensive weeding did not increase the efficiency of most weeding treatments, except for hand-weeding, hoe-weeding and rotary weeding with a hand-tractor. More intensive weeding also only slightly increased the total time requirements for weeding; this is especially significant for hoe-weeding (which is the customary weeding practice) in that one extra weeding and an early beginning does not increase the total weeding time over weeding at three and six weeks after planting. The time saved by using a hand-tractor for tine and blade weeding, compared to hand-pushing, is very small, while the efficiency is not better. This rules out, from an economic point of view, weeding with a hand-tractor, except if used in combination with a rotary weeding attachment. This latter proved very fast and most efficient of all the mechanical weed control practices tested.

The different tillage practices had a considerable influence on the time requirements for weeding, as indicated by Table 92.

Unfortunately, yields were again low due to drought stress, and varied from between 200 and 500 kg/ha (variety: IR528).

FIG. 64. Hand-pushed tine weeder

FIG. 65. Mechanical weed control in upland rice with a two-wheel tractor.

FIG. 66. Small tractor for rotary weeding in upland rice.

TABLE 92. Total time requirements in hrs/ha for twelve weeding treatments following three methods of land preparation.

Weeding treatment	Strip tillage	Tine cultivation	Ploughing + harrowing
1. HaW, 2 ×	525	481	407
2. HaW, 3 ×	623	539	457
3. HoW, 2 ×	282	282	193
4. HoW, 3 ×	304	265	226
5. TWH, 2 ×	72	62	55
6. TWH, 3 ×	86	85	79
7. TWT, 3 ×	57	54	52
8. BWH, 3 ×	89	83	80
9. BWT, 3 ×	70	66	63
10. RSH, 3 ×	438	342	262
11. RWT, 2 ×	34	29	26
12. RWT, 3 ×	37	33	31

From the two foregoing trials, it was decided that mechanical weed control methods alone are not effective enough to control weeds adequately in upland rice.

Another experiment was therefore set up to study whether combinations of manual and mechanical methods could be of interest. Some selected herbicides were also used in the experiment as comparison. Avirosan, applied two days after planting before emergence at 2 kg a.i. per hectare, and Propanil, applied three weeks after emergence at 2 kg a.i. per hectare, were used as herbicides. As reported (IITA, 1973 and IITA, 1974), this combination showed good promise for rice on well-drained and poorly-drained soils.

The twelve treatments applied in the experiment were:

1. No weeding (NoW)
2. Weed-free (weekly weeding) (WFree)
3. Hoe-weeding, 3 and 6 weeks after planting (HW, 2 ×)
4. Hoe-weeding, 2, 4½ and 7½ weeks after planting (HW, 3 ×)
5. Tine weeding (hand-pushed), 2 weeks after planting; hoe-weeding, 4½ weeks after planting; hoe-weeding, 7½ weeks after planting (T_2; $H_{4½}$; $H_{7½}$)
6. Hoe-weeding, 2 weeks after planting; tine weeding (hand-pushed), 4½ weeks after planting; hoe-weeding, 7½ weeks after planting (H_2; $T_{4½}$; $H_{7½}$)
7. Tine weeding (hand-pushed), 2 weeks after planting; tine weeding (hand-pushed), 4½ weeks after planting; hoe-weeding, 7½ weeks after planting (T_2; $T_{4½}$; $H_{7½}$)
8. Rotary weeding (with hand-tractor), 2 weeks after planting; hoe-weeding, 4½ weeks after planting; hoe-weeding, 7½ weeks after planting (R_2; $H_{4½}$; $H_{7½}$)
9. Hoe-weeding, 2 weeks after planting; rotary weeding, 4½ weeks after planting; hoe-weeding, 7½ weeks after planting (H_2; $R_{4½}$; $H_{7½}$)
10. Rotary weeding, 2 weeks after planting; rotary weeding, 4½ weeks after

TABLE 93. Weed growth (in g/m^2), time requirements for weeding (in hrs/ha) and yields (in kg/ha) following twelve weeding treatments.

Weeding treatment	Weeks after planting[1]					Weeds at harv. g/m^2	Weeding time (hrs/ha)	Yields kg/ha	%
	2	3	4½	6	7½				
1. NoW						953	–	–	–
2. WFree						–	–	1708	95
3. HW, 2 ×		214 (68)		287 (208)		192	501	1344	75
4. HW, 3 ×	131 (14)		208 (33)		172 (73)	245	511	1672	93
5. T_2; $H_{4½}$; $H_{7½}$	26 (22)		387 (123)		171 (174)	316	584	1597	89
6. H_2; $T_{4½}$; $H_{7½}$	164 (41)		31 (41)		370 (305)	229	565	1503	83
7. T_2; $T_{4½}$; $H_{7½}$	25 (40)		44 (144)		401 (341)	413	470	941	52
8. R_2; $H_{4½}$; $H_{7½}$	9 (19)		274 (117)		181 (167)	240	464	1533	85
9. H_2; $R_{4½}$; $H_{7½}$	160 (32)		12 (53)		320 (234)	230	492	1418	79
10. R_2; $R_{4½}$; $H_{7½}$	10 (28)		12 (100)		402 (331)	397	424	1184	66
11. Ch, pe; H_3		66				256	76	1658	92
12. Ch, pe; $Ch_{3½}$						592	20	1801	100
Significance level:								1%	
LSD (.05)								214	

[1] In colums 2–6, the first figure is time in hrs/ha; the figure in parenthesis is weed weight in g/m^2 at the time of the treatment.

planting; hoe-weeding, 7½ weeks after planting (R_2; $R_{4\frac{1}{2}}$; $H_{7\frac{1}{2}}$)

11. Avirosan, 2 days after planting; hoe-weeding, 3 weeks after planting (Ch, pe; H_3)
12. Avirosan, 2 days after planting; Propanil, 3½ weeks after planting (Ch, pe; $Ch_{3\frac{1}{2}}$)

Weed growth and time requirements were measured and are presented in Table 93. The yields were reasonably high and are also given in the same table (Variety: OS6). Weed growth was tremendous, 953 g/m² or about 10,000 kg dry weight per ha in the non-weeded plots, and the yield in this treatment was consequently zero. Three hoe-weedings resulted in a yield increase of about 25% over two hoe-weedings, while the total time required was the same for both.

One mechanical weeding in combination with two hoe-weedings results in a slight yield reduction ,while two mechanical weedings in combination with one hoe-weeding result in a considerable yield reduction as compared to hoe-weeding alone. Mechanical weeding as first treatment appeared to be slightly better than when applied as a second operation.

The time saved by using mechanical methods in combination with hoe-weeding as compared to hoe-weeding alone is very small.

The exclusive chemical treatment contained a fair amount of weeds at harvest time, but yielded highest and the time required was only 20 hrs/ha for the two sprayings.

The combination of Avirosan and one hoe-weeding at three weeks after planting also proved superior in yield level and time requirement over the manual and mechanical weed control methods.

It was concluded from this experiment that mechanical inter-row weed control methods can only play, if any, a very limited role in upland rice and that chemical weed control alone or in combination with manual weeding are most promising for high yields and low time requirements; manual weed control is very effective, if done in time, but requires much labour.

5.5.2. *Weed growth aspects*

Following the failure of mechanical weed control methods to provide adequate weed control, an experiment was conducted to study the inter-row and intra-row weed growth and the effect on the yields of rice.

Ten weeding treatment were applied in a randomized complete block design with four replications. The experiment was conducted on a hydromorphic soil. The row distance was 30 cm; intra-row was regarded as being a strip of 8–10 cm, 4–5 cm on each side of the row, while the remaining part of 20–22 cm between the rows was regarded as inter-row. The weedings were done at three and six weeks after planting.

The yield data and the weed weights at harvest are given in Table 94. The results indicate that neither inter-row nor intra-row weeding are adequate enough and that complete weeding has to be done for high yields. The results also prove that mechanical weed control practices alone, leaving the intra-row

TABLE 94. Yields in kg/ha and weed growth at harvest in kg dry weight per ha following ten weeding treatments.

Weeding treatments	Yields		Weed weight at harvest (kg/ha)		
	kg/ha	%	intra-row	inter-row	total
1. Weed-free	3753	100	–	–	–
2. Complete, fb complete	3037	81	422	1056	1476
3. Inter-row, fb complete	1847	49	756	1611	2367
4. Complete, fb inter-row	1476	39	1762	982	2744
5. Inter-row, fb intra-row	857	23	1390	3125	4515
6. Inter-row, weekly	677	18	4299	–	4299
7. Intra-row, fb inter-row	616	16	1380	2986	4366
8. Inter-row, fb inter-row	382	10	3222	2806	6028
9. Intra-row, weekly	51	1	–	4897	4897
10. Intra-row, fb intra-row	22	1	905	5568	6473
Significance level	1%				
LSD (.05)	685				

fb = followed by

weed growth intact, cannot be effective for rice grown under conditions of no water control.

5.5.3. *Discussion*

Field experiments with upland rice have shown that mechanical weed control practices are not effective enough in controlling weed growth sufficiently. Manual weeding is very effective, but requires a lot of time. A combination of mechanical weed control and manual weeding yielded lower and reduced the total labour requirements only slightly compared to manual weeding alone. Chemical weed control resulted in the highest yields and the labour requirements are low; also a combination of chemical weeding (applied at pre-emergence) and manual weeding (at three weeks after planting) proved very effective and required only about 75 hrs/ha.

A model experiment with inter-row and intra-row weed control treatments proved that neither inter-row nor intra-row weeding alone are effective, while combinations of these treatments with complete weeding resulted in considerable yield losses compared to two subsequent manual weedings. This experiment confirmed that mechanical weed control cannot be effective in upland rice and that mechanical weeding in combination with manual weeding will result in yield reduction compared to manual weeding alone.

Because of the high labour requirements for manual weeding, it may be expected that, for upland rice grown on a larger scale, chemical methods alone or in combination with manual weeding will be the best solution.

6. SUMMARY

Introduction

Mechanization in West Africà has been of limited importance and influence for farming and manual labour is the dominant power input. At present only about 0.07 kW per ha is applied, while at least about 0.37 kW is desirable to obtain high yield levels.

In this mechanization study a review is given of the inter-relationships of socio-economic and agro-ecological factors with agricultural development and with agricultural mechanization in particular and of the different forms of and policies on mechanization (Chapter 2). Some model studies on mechanization are reported, which indicate the importance and constraints of soil tillage and weed control for most mechanization levels. The model study on vegetables also indicated the importance of different land preparation practices on yields (Chapter 3). Soil tillage studies were therefore carried out, with the emphasis on rice (Chapter 4). These studies were conducted in several places along a typical toposequence, from purely upland (rainfed) conditions to irrigated conditions. The weed growth effects of different tillage practices are reviewed and the results with manual and mechanical weed control practices in rice are indicated (Chapter 5).

Principles of mechanization and mechanization stategy

Mechanization has obvious advantages, but can also have disadvantages. The most important advantages are: increased land and labour productivity, increased yields, higher profits, reduced costs, reduction of drudgery and reduced losses (2.3). The most important constraints are related to socio-economic and technical factors (2.3). Socio-economical problems are also the most prohibiting to the introduction of new technology (2.4).

Four levels of mechanization can be distinguished: manual labour, animal draught, small-scale mechanization based on small tractors and large-scale mechanization based on standard four-wheel tractors (2.5). Manual labour is cheap, but offers serious limitations for increased area under cropping and for increasing cropping intensities (2.5.2). Animal draught cannot be applied in the humid parts of West Africa, because of *Trypanosomiasis*; in the savannah areas it is locally available and relatively cheap, while it can help increase the area under cropping (2.5.3). Two-wheel tractors have not found any significant application in West Africa; they can offer serious ergonomical disadvantages, while the costs per hp and per ha are high. It is argued that small four-wheel tractors should be pursued instead (2.5.4.3). So far mechanical power in Africa has come almost exclusively from standard four-wheel tractors. Their application has had considerable impact in some instances, while in other cases they have been failures, due to inadequate planning, management and support and because other necessary conditions were not met (2.5.4.4).

Four mechanization 'philosophies' are reviewed (2.6).

Intermediate, or sometimes called appropriate, technology is a term used to describe a technology which is compatible with the prevailing socio-economic and technical local conditions and most advocates also argue that this type of technology should be designed in such a way, that it can be made locally from locally available materials (2.6.2).

Selective mechanization, sometimes indicated as partial mechanization, emphasizes that mechanization should only be applied under those conditions or situations and during those stages in the production-marketing process, where labour is the limiting factor (2.6.3).

Tractor hiring services have been the main means by which mechanical power until now has been applied in West Africa; they are based on standard four-wheel tractors. These hiring services are usually started as Government operated units and it is argued that these should be handed over to private individuals as soon as possible (2.6.4).

Large-scale farming with large-scale equipment has been exercised by various Governments in West Africa and its performance has been mostly negative, due to socio-economic and agro-ecological, as well as technical, restrictions. It is argued that intensification, rather than developing new large-scale projects, is a more secure and faster way of increasing food production (2.6.5).

Some aspects of the agro-ecology and the socio-economics are reviewed (2.7). It is emphasized that soils and crops have to be selected well before mechanization is applied. The mechanization potentialities are indicated to be best for hydromorphic areas and for rice (2.7.2), and it is argued that irrigation developments will stimulate mechanization most.

Cost calculations for the different levels of mechanization are made and they indicate that, although the costs per hour are lower for two-wheel tractors, the costs per hp and per hectare (for soil tillage) are lower for standard four-wheel tractors (2.7.3.1).

The importance of the ergonomical aspects (2.7.3.2.), as well as of the social acceptability of new technology is indicated (2.7.3.3).

The effect of mechanization on employment is reviewed (2.8). It is argued that mechanization undoubtedly can create unemployment or increased under-employment under certain conditions, but that the introduction of irrigation and the new seed-fertilizer technology coupled with a selective introduction of mechanization increases rather than reduces labour requirements. So far, mechanization in West Africa has not shown any serious labour displacing effects.

In the general discussion (2.9) it is argued that for West African conditions private tractor hiring units could possibly be the best solution for the short and medium term basis, to get mechanization developments started. In this way mechanization will be introduced selectively, since the farmers decide for which operations they want the mechanization services applied.

Intermediate technology may start slowly as the technical capabilities and the socio-economic acceptability of the new technology develop in the rural areas and it can be visualized that on a medium and long term basis this type of technology will supplement the basic (mainly soil tillage) operations, as carried out by the standard four-wheel tractors of the hiring services. The scope for two-wheel tractors seems limited, although their application in hydromorphic valleys with rice or in market gardening seems to be feasible. It is argued that small four-wheel tractors instead could possibly find easier application and acceptance.

It is concluded that farming in West Africa will mainly depend, for many years to come, on manual labour and that mechanization will become increasingly important, as soon as a 'Green Revolution' is set in motion.

Model studies on mechanization systems

Two model studies are reported. The first study concentrated on rice and made use of available data on time and labour requirements for the various operations in the production process for different levels of mechanization (3.2). The second study was a field study with vegetables, in which all inputs were recorded and yields were measured (3.3).

The main purpose of the model studies was to determine which operations in the production process are most limiting to an increased area under cropping for different mechanization levels, while an additional objective in the second study was to investigate the effects of different mechanization levels on yields and profitability.

The rice mechanization study indicated that, although transplanting and harvesting and threshing can offer restrictions, in general soil tillage and weed control are the major limiting factors for all steps in mechanization development; these two operations claim between 40 and 60% of the total labour requirements.

The field study with vegetables, where two mechanization levels were applied, also indicated that soil tillage and weed control were major bottlenecks; in the manual system soil tillage and weeding were equally limiting, taking together as an average about 54% of the total input hours, while in the tractor system weed control was far more limiting than soil tillage, taking on average about 29% of the total labour requirements, about 25% of which for weeding. This study demonstrated the effects of different land preparation practices, inherent to the two mechanization systems, on yields; while most crops reacted positively to the tractor tillage (about 15–20 cm deep), some crops reacted favourably to the shallow manual hoeing (about 4–6 cm deep). In general, this field study indicated that growing vegetables under the tractor system resulted in higher yields, lower production costs and higher net income per manhour of labour input than under the manual system.

Soil tillage

Soil tillage and weed control are studied in more detail in this mechanization study, because they are usually the major limiting factors in the crop production process, because most mechanized inputs in West African agriculture have so far been in land preparation, and because soil tillage studies and recommendations can have considerable effects on the desirable level and type of mechanization (4.1).

Soil tillage studies were carried out in several places along a typical toposequence, which consists of three major soil groups: the plateau soils (well-drained), the lower slope soils (well-drained) and the valley soils (poorly-drained).

Well-drained soils

Two experiments were conducted on the plateau soils, a five-year long experiment on Egbeda soil, which was newly-cleared (4.4.3.2), and a one-year experiment on Iwo soil, which had been cleared for one year (4.4.3.3).

On the plateau soils zero or minimum tillage techniques may be feasible if enough crop residues are available. Without crop residues these techniques perform poorly. Deep tillage practices are not to be recommended, as they turn up gravel and expose the bare soil, which can result in surface crusting and poor germination. Deep tillage practices may, however, appear to be fair treatments during the first few years after clearing. Shallow tillage techniques yielded highest in the experiments for rice and maize and can also protect the soil well against erosion, if enough crop residues are available and if they are mixed in the surface layer (4.4.3.2.1).

The bulk density showed a considerable increase over a five-year period, and the pore volume decreased accordingly (4.4.3.2.2). Mulching had a positive effect on quantitative root growth, and deep tillage practices resulted in reduced root growth for rice and maize in the 0–10 cm layer, while zero tillage showed a reduced root growth in the 10–20 cm layer for rice. In general, shallow tillage techniques resulted in more quantitative root growth than the other tillage practices (4.4.3.2.2). Soil moisture, which had become a limiting factor because of the increased bulk density, was highest following shallow tillage; zero tillage resulted in the lowest soil moisture, while deep tillage conserved soil moisture best, resulting in less wilting during dry periods. Mulching increased soil moisture and the water-holding capacity (4.4.3.2.4 and 4.4.3.2.5). Deep tillage resulted in a reduced number of plants and delayed maturity (4.4.3.2.6). Mulching increased the infiltration rates, and infiltration was highest for zero tillage, followed by deep tillage and shallow tillage (4.4.3.2.7). The most important soil chemical changes were a reduction in pH and available P (4.4.3.2.8).

Differences in nutrient uptake by the plants for the different treatments could not be detected (4.4.3.2.9).

On the lower slope soils a two-year experiment was conducted on Iregun soil, which had one crop of maize after land-clearing before the experiment was started (4.4.4.2). As compaction already occurs under natural forest conditions, zero tillage rechniques will not perform well. Bulk densities following ploughing (20 cm deep) were considerably lower than following zero and shallow tillage, especially in the 10–20 cm layer (4.4.4.2.2), and root growth was much better following ploughing (4.4.4.2.3). Ploughing showed a higher soil moisture (4.4.4.2.4) and a higher water-holding capacity than zero and shallow tillage (4.4.4.2.5). Plant growth was significantly higher following ploughing (4.4.4.2.6). Infiltration rates were highest following ploughing (4.4.4.2.7). Chemical changes in comparison to the natural conditions could not be measured, although the pH and the available P appeared to have decreased (4.4.4.2.8). Plant tissue analysis did not indicate any difference between the tillage treatments (4.4.4.2.9).

The effect of mulching on soil physical characteristics was less clear on the lower slope soil compared to the plateau soil; mulching did not appear to have an effect on soil chemical properties of both soils.

Poorly-drained soils

On the poorly-drained soils without water control soil tillage to a reasonable depth (about 15 cm) resulted in higher yields than zero tillage during the wet season, while during the dry season zero tillage yielded higher, although the yield levels then were much lower (4.5.2.1). Mulching in general had a negative rather than a positive effect on yields. Good water management proved to be the most important factor for high yields (4.5.2.3). On poorly-drained soils with water control three series of experiments were conducted.

The first, comparing wet and dry tillage on newly developed paddy lands, showed that wet tillage results in significantly higher yields than dry tillage on the light, sandy loam soils where the creation of a plough-pan, which can be done most quickly through wet tillage practices, is important to reduce leaching losses (4.5.3.4). A description of the layer stratification in puddled soil is given (4.5.3.4.3).

The second series of experiments dealt with the timing of wet land preparation in relation to different amounts of rice straw to be incorporated (4.5.3.5). These experiments did not indicate any significant effect of different tillage times or of increased amounts of incorporated rice straw, although there were some indications that primary tillage at about two weeks before sowing or transplanting seemed to offer minimum risks (4.5.3.5.1).

The third series studied different wet tillage practices on sandy, loamy and clayey soil types (4.5.3.6). Zero tillage techniques, which hardly create a plough-pan, resulted in lower yields, especially on the lighter soils. Intensive puddling or ploughing and harrowing during the first crops after land development, created the desired plough-pan most quickly and resulted in the highest yields, while during the subsequent crops less intensive tillage practices yielded equally high as intensive tillage. The % increase due to nitrogen application was highest for the lightest soil and also highest for zero tillage (4.5.3.6.1). These results show the importance of tillage-nitrogen interactions, especially with zero tillage techniques.

Weed control

Tillage effects on weed growth were studied and showed that deep tillage treatments resulted in less weed growth than shallow tillage techniques, while zero tillage resulted in the most quantitative weed growth (5.4.1). Tillage at the end of the wet season did not reduce the amount of weeds grown compared to the conventional tillage at the beginning of the wet season, although there was a marked change in the weed species grown following these two treatments (5.4.1).

On poorly-drained soils, good water control and intensive puddling or ploughing with harrowing were most effective in reducing the weed growth (5.4.2).

Manual and mechanical weeding practices were compared under upland conditions with rice (5.5.1) and indicated that manual weeding is very effective, but requires a lot of time, and that mechanical inter-row weeding is not very effective. Also in combination with manual weeding, mechanical weeding did not result in reduced labour requirements, compared to manual weeding alone, while the yields were reduced.

A model experiment with inter-, intra-row and complete weeding treatments indicated the same results and it was concluded, therefore, that mechanical weeding methods are of little or no use with upland rice.

Chemical weed control methods, either alone or in combination with manual weeding, yielded highest, while the labour requirements were fairly low.

Conclusion

Mechanization of West African agriculture is only at a starting point, but its importance will increase considerably, if and when the prevailing subsistence farming becomes commercialized agriculture.

Soil tillage and weed control are the main limiting factors in the production process of most crops.

Soil tillage requirements vary for different soil types and can have an effect on the desired level and type of mechanization.

Weed control is a serious problem and alternative methods to manual weeding are needed.

SAMENVATTING

In West Afrika is de landbouwmechanisatie slechts weinig ontwikkeld en handarbeid is nog het meest gebruikelijk. Per hectare wordt slechts ongeveer 0,07 kW toegepast, terwijl tenminste ongeveer 0,37 kW wenselijk is om hoge opbrengstniveaus te bereiken.

Deze studie geeft in hoofdstuk 2 een overzicht van het verband tussen sociaal-economische en agrologische faktoren en landbouwkundige ontwikkeling, met speciale nadruk op de landbouwmechanisatie. In hoofdstuk 3 worden de resultaten vermeld van model-studies over mechanisatie, die het belang en de areaal beperkende invloed van grondbewerking en onkruidbestrijding aantonen. De model-studie met groenten geeft bovendien aan dat verschillende grondbewerkingsmethoden een vrij sterke invloed kunnen hebben op de opbrengsten. Daarom werden grondbewerkingsproeven uitgevoerd met rijst als belangrijkste gewas. Deze studies werden gedaan op verschillende plaatsen langs een typische 'toposequence', die gaat van droge tot natte geïrrigeerde omstandigheden (hoofdstuk 4). In hoofdstuk 5 wordt het effekt van de verschillende grondbewerkingsmethoden op de onkruidgroei behandeld, alsook de resultaten van het in handwerk of door middel van werktuigen bestrijden van het onkruid in rijst.

Landbouwmechanisatie en zijn toepassingsmogelijkheden

Mechanisatie heeft naast duidelijke voordelen ook nadelen. De belangrijkste voordelen zijn: hogere produktiviteit van grond en arbeid, hogere opbrengsten, verhoogde inkomsten, lagere kosten, vermindering van de lichamelijke inspanning en lagere verliezen aan het produkt. De belangrijkste beperkingen liggen op het sociaal-economische en technische vlak.

Men kan vier mechanisatieniveaus onderscheiden: handkracht, dierlijke trekkracht, kleinmechanisatie, gebaseerd op kleine trekkers, en grootmechanisatie, gebaseerd op standaard vierwielige trekkers.

Handkracht is goedkoop maar kan slechts in beperkte mate bijdragen tot areaalvergroting en tot het overschakelen op intensievere teelten.

Dierlijke trekkracht kan niet worden toegepast in de natte tropen van West Afrika, vanwege *Trypanosomiasis*; in de savanne gebieden is dierlijke trekkracht echter wel aanwezig en relatief goedkoop.

Tweewielige trekkers worden slechts op zeer beperkte schaal toegepast in West Afrika; ze kunnen ernstige ergonomische nadelen hebben, terwijl de kosten per kW en per hectare hoog zijn. Er wordt dan ook voor gepleit om meer aandacht te schenken aan kleine vierwielige trekkers.

Motorische kracht, toegepast in West Afrika, is tot nu toe uitsluitend gekomen van standaard vierwielige trekkers. Dit is deels met succes gebeurd en deels op mislukkingen uitgelopen.

Een overzicht wordt gegeven van vier 'filosofieën' met betrekking tot de landbouwmechanisatie.

Intermediate, soms genoemd aangepaste technologie is een technologie, die aansluit bij de heersende sociaal-economische en lokale technische omstandigheden; de meeste voorstanders pleiten er voor dat deze technologie zo moet zijn, dat ze ter plaatse kan worden gemaakt van voornamelijk ter plaatse aanwezige materialen.

Selectieve, ook wel genoemd partiële mechanisatie legt er de nadruk op dat mechanisatie alleen onder die omstandigheden en situaties en in die gedeelten van het produktie- en verkoopproces moet worden toegepast, waar arbeid de beperkende faktor is.

Motorische kracht is in West Afrika tot nog toe voornamelijk toegepast door middel van loondiensten, die gebaseerd zijn op standaard vierwielige trekkers. Deze diensten worden doorgaans opgezet door de regering en er wordt voor gepleit om deze diensten zo spoedig mogelijk over te geven in privé beheer.

Landbouw op grote schaal is door verschillende regeringen in West Afrika beoefend, maar is meestal op een mislukking uitgelopen. Intensievering van gebruik van bestaande landbouwgronden lijkt een veiligere en snellere manier om tot verhoogde voedselproduktie te komen dan het op grote schaal ontginnen van nieuwe landbouwgrond.

Enkele agrologische en sociaal-economische aspekten zijn bekeken. Er is de nadruk op gelegd dat gronden en gewassen goed geselekteerd moeten worden alvorens mechanisatie wordt toegepast. Er wordt aangegeven dat de mogelijkheden voor mechanisatie het beste zijn op hydromorfe gronden en voor rijst en dat ontwikkelingen op het gebied van de irrigatie het meest stimulerend zullen werken om tot mechanisatie te komen.

Kostenberekeningen voor de verschillende mechanisatieniveaus zijn gemaakt, welke aangeven dat de kosten per kW en per hectare lager zijn voor standaard vierwielige trekkers dan voor tweewielige trekkers, hoewel de kosten per uur voor tweewielige trekkers lager zijn.

Er wordt gewezen op het belang van de ergonomische aspekten en van het sociaal acceptabel zijn van nieuwe technologieën.

Een overzicht wordt gegeven van het effekt van mechanisatie op de werkgelegenheid. Er is op gewezen dat mechanisatie ongetwijfeld werkeloosheid kan scheppen of een groter werktekort onder bepaalde omstandigheden, maar dat de invoering van irrigatie en de nieuwe hoogwaardige rassen en kunstmest tezamen met een selektieve toepassing van mechanisatie daarentegen de arbeidsbehoefte eerder verhoogt dan verlaagt. Tot dusver heeft mechanisatie in West Afrika geen ernstige arbeidsvervangende effekten getoond.

In de algemene diskussie wordt geargumenteerd dat voor Westafrikaanse omstandigheden privé loonbedrijven wellicht de beste oplossing zijn voor de korte en middellange termijn om landbouwmechanisatie van de grond te krijgen. Op deze manier zal mechanisatie selektief worden geïntroduceerd, aangezien de boeren zelf beslissen voor welke werkzaamheden ze de diensten noodzakelijk achten. 'Intermediate technology' kan langzaam beginnen naarmate de technische mogelijkheden en de sociaal-economische omstandigheden op het platteland beter worden. Op de middellange en lange termijn kan deze technologie de basisbewerkingen, uitgevoerd door de vierwielige trekkers van de loonbedrijven, aanvullen. De vooruitzichten voor tweewielige trekkers lijken beperkt, ofschoon ze wel toegepast kunnen worden in hydromorfe valleien met rijst of in de voor de markt producerende volkstuinbouw. Wellicht zijn er betere mogelijkheden voor kleine vierwielige trekkers om geaccepteerd en toegepast te worden.

Tot slot wordt opgemerkt, dat de landbouw in West Afrika nog vele jaren afhankelijk zal zijn van handkracht en dat mechanisatie van meer belang zal worden zodra de Groene Revolutie ook daar op gang is gebracht.

Model studies over mechanisatie

Verslag is gedaan van twee model studies. De eerste handelt over rijst en daarin is gebruik gemaakt van bestaande gegevens over arbeidstijden en arbeidsbehoeften voor de verschillende werkzaamheden in het produktieproces voor diverse mechanisatieniveaus. De tweede studie is een veldstudie met groentes, waarbij alle inputs werden genoteerd en de opbrengsten werden gemeten.

Het belangrijkste doel van deze model studies was om te bepalen welke bewerkingen in het produktieproces het meest beperkend zijn om tot een groter bebouwd oppervlakte te komen voor de verschillende mechanisatieniveaus; in de tweede studie was het doel bovendien om het effekt van de verschillende mechanisatiesystemen op opbrengsten en netto inkomsten te bestuderen.

Uit de mechanisatiestudie met betrekking tot de rijstteelt bleek dat, alhoewel overplanten en oogsten en dorsen beperkend kunnen zijn, in het algemeen grondbewerking en onkruidbestrijding de belangrijkste beperkende faktoren zijn voor alle stappen in de ontwikkeling van mechanisatie; deze twee bewerkingen vragen tussen de 40 en 60% van de totale arbeidsbehoeften.

De veldstudie met groentes, waarbij twee mechanisatieniveaus werden toegepast, gaf ook aan dat grondbewerking en onkruidbestrijding de belangrijkste knelpunten waren; in het systeem met handwerk waren grondbewerking en onkruidbestrijding in gelijke mate beperkend, tezamen ongeveer gemiddeld 54% vergend van de totale arbeidsuren, terwijl in het trekkersysteem onkruidbestrijding veel meer beperkend was dan grondbewerking. Tezamen vragen ze dan gemiddeld 29% van de totale arbeidsbehoefte, waarvan ongeveer 25% voor onkruidbestrijding. Deze studie demonstreert het effekt van verschillende grondbewerkingsmethoden, inherent aan de twee mechanisatieniveaus, op de opbrengsten; terwijl de meeste gewassen positief reageerden op de diepere grondbewerking met de trekker (ongeveer 15–20 cm), reageerden enkele gewassen positief op de ondiepe grondbewerking met de hak (ongeveer 4–6 cm), vooral als er voldoende gewasresten aanwezig waren.

In het algemeen gaf deze veldstudie aan dat het verbouwen van groenten bij het trekkersysteem resulteerde in hogere opbrengsten, lagere produktiekosten en een hoger netto inkomen per manuur arbeid dan bij het handsysteem.

Grondbewerking

Grondbewerking en onkruidbestrijding zijn meer gedetailleerd bestudeerd in deze mechanisatiestudie, omdat ze doorgaans de belangrijkste beperkende bewerkingen zijn in het produktieproces van gewassen. De meeste inputs op mechanisatiegebied in de Westafrikaanse landbouw zijn tot nu toe op het gebied van de grondbewerking geweest. Studies met betrekking tot grondbewerking kunnen tot aanbevelingen leiden, die aanzienlijk konsekwenties kunnen hebben op het wenselijke type en niveau van mechanisatie.

Grondbewerkingsstudies werden uitgevoerd op verschillende plaatsen langs een typische 'toposequence', die bestaat uit drie belangrijke bodemgroepen: de topgronden boven op de helling (goed gedraineerd), de gronden lager op de helling (goed gedraineerd) en de valleigronden (slecht gedraineerd).

Goed gedraineerde gronden

Twee proeven werden uitgevoerd op de topgronden: een vijfjarenproef op Egbeda grond, die pas ontgonnen was en een eenjarige proef op Iwo grond, die een jaar tevoren was ontgonnen.

Op de topgronden kunnen methoden, die gebaseerd zijn op vastegrondteelt of op minimale grondbewerking, mogelijk zijn als genoeg gewasresten beschikbaar zijn om als mulch te dienen; zonder gewasresten blijken deze methoden onbevredigende resultaten op te leveren. Diepe grondbewerkingsmethoden zijn hier niet aan te bevelen, aangezien ze grint naar boven brengen en de kale grond blootstellen wat kan resulteren in korstvorming en slechte ontkieming. Diepe grondbewerkingen kunnen echter redelijk lijken gedurende de eerste paar jaren na ontginning. Ondiepe grondbewerkingen gaven de hoogste opbrengsten in de proeven, zowel voor rijst als mais, en bleken bovendien, als er genoeg gewasresten beschikbaar waren om met de oppervlaktelaag vermengd te worden, de grond goed tegen erosie te beschermen.

De dichtheid van de grond vertoonde een aanzienlijke toename over de vijfjarige periode.

Mulchen had een positieve invloed op de kwantitatieve wortelgroei. In het algemeen resulteerden de ondiepe grondbewerkingsmethoden in meer kwantitatieve wortelgroei dan de andere methoden.

Het vochtgehalte van de grond, dat een beperkende faktor was geworden door de toegenomen dichtheid, was het hoogst bij ondiepe bewerking; vastegrondteelt resulteerde in het laagste vochtgehalte, terwijl het waterhoudende vermogen het beste was bij de diepe bewerking. Dit resulteerde in minder verwelkingsverschijnselen gedurende droge perioden. Mulchen verhoogde het vochtgehalte alsook het waterhoudend vermogen van de grond.

Het aantal gekiemde planten was lager en de afrijping vertraagd bij diepe grondbewerking.

Mulching verhoogde de infiltratie. De infiltratie was het hoogst bij vastegrondteelt, gevolgd door diepe en ondiepe grondbewerking.

De meest belangrijke bodemchemische veranderingen waren een afname van pH en beschikbare P. Verschillen in opname van voedingsstoffen door de planten als gevolg van de verschillende grondbewerkingsmethoden konden niet worden bespeurd.

Op de gronden lager op de helling werd een tweejarige proef uitgevoerd op Iregun grond, waarop een gewas mais had gestaan na ontginning van de grond, voordat de proef werd gestart. Deze gronden vertonen al een grotere dichtheid in de diepere lagen onder natuurlijk bos en vastegrondteelt kan daarom niet met succes worden toegepast. De dichtheden na ploegen (20 cm) waren aanzienlijk lager dan na ondiepe bewerkingen en vastegrondteelt, vooral in de 10–20 cm laag. De wortelgroei en de groei van het gewas waren na ploegen veel beter. Geploegde velden vertoonden een hoger vochtgehalte en een groter waterhoudend vermogen dan ondiep bewerkte velden of velden met vastegrondteelt.

Infiltratie was het hoogst na ploegen.

Bodemchemische veranderingen in vergelijking tot de natuurlijke omstandigheden onder bos konden niet worden vastgesteld, alhoewel de pH en de beschikbare P afgenomen leken te zijn. De verschillende grondbewerkingsmethoden hadden geen invloed op de chemische samenstelling van het plantweefsel.

Het effekt van mulchen op de bodemfysische eigenschappen was veel minder duidelijk voor de gronden lager op de helling in vergelijking met de topgronden; mulchen vertoonde geen aanwijsbare effekten op de bodemchemische eigenschappen bij beide bodemtypen.

Slecht gedraineerde gronden

Op de slecht gedraineerde gronden zonder waterbeheersing resulteerde grondbewerking tot een diepte van ongeveer 15 cm in hogere opbrengsten dan vastegrondteelt in het natte seizoen, terwijl gedurende het droge seizoen de vastegrondteelt hogere opbrengsten gaf, alhoewel de opbrengstniveaus dan wel veel lager waren. Mulchen vertoonde in het algemeen eerder een negatieve dan positieve invloed op de opbrengsten. Goede waterbeheersing bleek de belangrijkste faktor te zijn om tot hoge opbrengsten te komen.

Op de slecht gedraineerde gronden met volledige waterbeheersing werden drie series proeven uitgevoerd. De eerste, waarbij natte en droge grondbewerking werden vergeleken met pas ontgonnen en voor de rijstteelt ingerichte gronden, toonde aan dat natte grondbewerking signifikant hogere opbrengsten gaf dan droge grondbewerking op de lichte, zandige leemgronden. Hierbij is de vorming van een ploegzool, die het snelst ontstaat door natte grondbewerking, belangrijk om verliezen aan water en daarmee aan voedingsstoffen te verminderen. Een beschrijving van de stratifikatie van lagen in gemodderde grond is gegeven.

De tweede serie proeven handelde over de tijd van grondbewerking vóór het zaaien en planten en het verband met verschillende hoeveelheden in te werken rijststro. Deze proeven vertoonden geen signifikante verschillen voor de verschillende tijden en hoeveelheden ingewerkt stro, ofschoon er enige aanwijzigingen waren dat bij een eerste grondbewerking ongeveer twee weken voor zaaien of planten de risiko's tot een mogelijke opbrengstdaling het minst zijn.

In de derde serie proeven werden natte grondbewerkingsmethoden bestudeerd op zandige, lemige en kleiïge gronden. Vastegrondteelt, waarbij nauwelijks een ploegzool wordt gevormd, resulteerde in lagere opbrengsten, speciaal op de lichtere gronden. Intensief modderen of ploegen met eggen gedurende de eerste gewassen na ontginning vormde de gewenste ploegzool het snelst en resulteerde in de hoogste opbrengsten, terwijl gedurende de volgende gewassen ook minder intensief modderen even hoge opbrengsten gaf als intensief modderen.

De procentuele toename in opbrengsten door stikstofgebruik was het hoogste voor de lichtste grond en bij vastegrondteelt. Deze resultaten geven het belang aan van de interaktie tussen grondbewerking en stikstof, speciaal bij minimale grondbewerking en vastegrondteelt.

Onkruidbestrijding

De invloed van verschillende grondbewerkingsmethoden op de onkruidgroei is bestudeerd en toont aan dat op de droge gronden diepe grondbewerking resulteert in minder onkruidgroei dan ondiepe bewerking, terwijl vastegrondteelt de meeste kwantitatieve onkruidgroei tot gevolg heeft. Grondbewerking op het eind van de natte tijd gaf geen vermindering in de onkruidgroei in vergelijking met de gangbare grondbewerking in het begin van de natte tijd. Wel was er een opvallende verandering in de soorten onkruid bij deze twee bewerkingen.

Op slecht gedraineerde gronden waren een goede waterbeheersing en intensief modderen of ploegen met eggen het meest effektief in het beperken van de onkruidgroei.

Onkruidbestrijdingsmethoden met de hand en door middel van werktuigen werden vergeleken op droge gronden met rijst. Deze gaven aan dat handwieden zeer effektief is, maar veel tijd vergt. Mechanisch wieden tussen de rijen door middel van werktuigen bleek niet erg effektief te zijn. Ook kombinaties van handwieden met mechanische methoden door middel van werktuigen verminderden de arbeidsbehoeften niet in vergelijking tot handwieden alleen, terwijl de opbrengsten lager waren.

Een modelproef, waarbij het onkruid alleen tussen de rijen of alleen binnen de rijen werd bestreden, en waarbij deze methoden ook gekombineerd en vergeleken werden met een volvelds onkruidbestrijding, gaf dezelfde resultaten aan. De konklusie werd daarom getrokken dat onkruidbestrijdingsmethoden door middel van werktuigen van gering of geen belang zijn in droge rijst.

Konklusie

Mechanisatie in de Westafrikaanse landbouw verkeert pas in het beginstadium, maar het belang ervan zal aanzienlijk toenemen, als en wanneer de landbouw op meer kommerciële schaal bedreven gaat worden.

Grondbewerking en onkruidbestrijding zijn de belangrijkste beperkende faktoren in het produktieproces van de meeste gewassen.

Grondbewerkingsbehoeften variëren voor verschillende bodemtypen en kunnen invloed hebben op het gewenste type en niveau van mechanisatie.

Onkruidbestrijding vormt een ernstig probleem en alternatieve methoden voor handwieden zijn dringend nodig.

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APPENDIX I. Cost calculations for hand-labour, a two-wheel tractor and a four-wheel tractor ($).

A. *Hand-labour*

I. $ 0.20/hour	a) 200 hrs/ha	$ 40/ha
	b) 400 hrs/ha	$ 80/ha
II. $ 0.40/hour	a) 200 hrs/ha	$ 80/ha
	b) 400 hrs/ha	$ 160/ha

B. *Two-wheel tractor (8 HP)*

I. Price: $ 1,500.– Fixed costs: depreciation: 300
interest: 75
Total 375

Variable costs:

	Hours per year						
	100	200	300	500	750	1000	1500
Operator	35	70	105	175	262.50	350	525
Fuel	15	30	45	75	112.50	150	225
Repairs, etc.	100	150	200	250	275	300	350
Total V.C.	150	250	350	500	650	800	1100
F.C. + V.C.	525	625	725	875	1025	1175	1475
Cost/hour	5.25	3.13	2.42	1.75	1.37	1.18	0.98
Cost/ha 30 hrs.	157.50	93.90	72.60	52.50	41.10	35.40	29.40
50 hrs.	262.50	156.50	121.00	87.50	68.50	59.00	49.00

II. Price: $ 3,000.– Fixed costs: depreciation: 600
interest: 150
Total 750

Variable costs:

	Hours per year						
	100	200	300	500	750	1000	1500
Operator	35	70	105	175	262.50	350	525
Fuel	15	30	45	75	112.50	150	225
Repairs, etc.	200	300	400	500	550	600	700
Total V.C.	250	400	550	750	925	1100	1450
F.C. + V.C.	1000	1150	1300	1500	1675	1850	2200
Cost/hour	10.00	5.75	4.33	3.00	2.23	1.85	1.47
Cost/ha 30 hrs.	300.00	172.50	129.90	90.00	66.90	55.50	44.10
50 hrs.	500.00	345.00	216.50	150.00	111.50	92.50	73.50

C. *Four-wheel tractor (56 HP)*

I. Price: $ 6,000.– Fixed costs: depreciation: 1200
interest: 300

Total 1500

Variable costs:

	Hours per year						
	100	200	300	500	750	1000	1500
Operator	35	70	105	175	262.50	350	525
Fuel	105	210	345	525	787.50	1050	1575
Repairs, etc.	400	600	800	1000	1100	1200	1400
Total V.C.	540	880	1250	1700	2150	2600	3500
F.C. + V.C.	2040	2380	2750	3200	3650	4100	5000
Cost/hour	20.40	11.90	9.17	6.40	4.87	4.10	3.33
Cost/ha 3 hrs.	61.20	35.70	27.51	19.20	14.61	12.30	9.99
6 hrs.	122.40	71.40	55.02	38.40	29.22	24.60	19.98

II. Price: $ 10,000.– Fixed costs: depreciation: 2000
interest: 500

Total 2500

Variable costs:

	Hours per year						
	100	200	300	500	750	1000	1500
Operator	35	70	105	175	262.50	350	525
Fuel	105	210	315	525	787.50	1050	1575
Repairs, etc.	650	1000	1350	1600	1800	2000	2400
Total V.C.	790	1280	1770	2300	2850	3400	4500
F.C. + V.C.	3290	3780	4270	4800	5350	5900	7000
Cost/hour	32.90	18.90	14.23	9.60	7.13	5.90	4.67
Cost/ha 3 hrs.	98.70	56.70	42.69	28.80	21.39	17.70	14.01
6 hrs.	197.40	113.40	85.38	57.60	42.78	35.40	28.02

APPENDIX II. Costs and prices of inputs used in the field study with vegetables ($).

A. Hand-labour: $ 0.35/hr
B. Equipment:

	Small 4-wh. tractor	Plough	Disc harrow	Tine cultivator	Planters	Knapsack sprayer
Fixed costs:						
New price	3200	150	200	200	300	75
Depreciation	640	30	40	40	30	15
Interest (10%)	160	7.50	10	10	15	3.75
Sub-total	800	37.50	50	50	50	18.75
Variable costs:						
Hours per year	500	200	100	100	25	250
Fuel (0.20/l)	350					
Repairs, etc.	600	50	40	40	30	18.75
Sub-total	950	50	40	40	30	18.75
Total costs per year	1750	87.50	90	90	75	37.50
Costs/hour	3.50	0.44	0.90	0.90	3.00	0.15

C. Fertilizers: $ 31.50/ha for each application
Herbicides: $ 30.00/ha for each application
Insecticides: $ 10.00/ha for each application

Curriculum Vitae.

Na het behalen van het Gymnasium β in 1964 ging de auteur aan de Landbouwhogeschool in Wageningen studeren. Hij behaalde het kandidaatsexamen in de richting Landbouwtechniek in 1968. Het ingenieursexamen werd met lof afgelegd in 1970 met als hoofdvak de Landbouwwerktuigkunde en als bijvakken de Werktuigkunde, de Grondbewerking en de Marktkunde en het Marktonderzoek.

Na het afstuderen werkte hij vijf jaar op het International Institute of Tropical Agriculture in Ibadan, Nigeria, waarvan de eerste vier jaar als assistent deskundige van de Wereldvoedselorganisatie voor een 'Rijstmechanisatie-project' en het laatste jaar in dienst van voornoemd instituut ter afsluiting van het veldwerk en het onderzoek.

Gedurende de eerste helft van 1976 werd dit proefschrift in Nederland verder uitgewerkt en afgerond.